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ITS services for freight transport management in proximity of terminals and logistics hubs

Case study on the Port of Trieste

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Summary

Abstract

In this master's degree thesis, the objective is to identify the effects that may have the implementation of Intelligence Transport Systems (ITS) in order to solve the congestions problems concerning ports and related container terminals, such as long waiting times, saturation and decrease of system throughput. This thesis mainly focuses on the consequences in the surrounds of maritime terminals caused by the gigantism of container vessels: these ones in the past decades have had an exponential evolution.

The aim is to generate a general perspective of the situation and a possible solution, regardless of the chosen case study. The study was centered on the Port of Trieste, knowing that this is one of the most relevant and growing ports in Italy and the Mediterranean zone.

Three scenarios have been generated in order to describe the current situation of the traffic conditions, plus one scenario exposing the possible solution; this last one emerges thanks to the proposal of the adoption of a series of traffic management strategies; these include the possibility to present a local broadcast system which allows the port to share traffic events and travel time information, with the aim of distributing the condensed flows - that may appear in the peak hours - in a better way.

In the first part of the thesis an introduction about the "ship gigantism" and it is relationships with the state of art in literature on this topic is presented. Right after a presentation of the used software AIMSUN is presented; this is a traffic simulation software that helps to model and determine the conditions of the different scenarios. Thereafter, a presentation of the case study has been made, giving a brief contextualization about the city and the port characteristics. The last part presents the description, results, and discussion of the four scenarios followed by the conclusions.

Abstract

In questo lavoro di tesi di Master l'obiettivo è identificare gli effetti che possono avere l'implementazione di Intelligence Transport Systems (ITS) al fine di risolvere i problemi di congestione, come lunghi tempi di attesa, saturazione e decremento del throughput del sistema. La tesi è incentrata sulle preoccupanti conseguenze nei dintorni dei terminal marittimi provocate dal gigantismo delle navi portacontainer che negli ultimi anni ha avuto una crescita esponenziale.

Lo scopo è generare una prospettiva generale della situazione e una possibile soluzione; tuttavia, lo studio è stato centrato nel Porto di Trieste come mezzo per sviluppare il caso di studio tenendo in conto che è uno dei porti più rilevanti e in crescita in Italia e nell'area del Mediterraneo. Sono stati generati tre scenari per descrivere la situazione attuale delle condizioni del traffico e uno scenario che spiega la possibile soluzione, questo è stato suggerito pensando di sviluppare una serie di strategie di gestione del traffico presentando un sistema di trasmissione locale che permetta al porto di condividere informazione sugli eventi di traffico e sui tempi di percorrenza, con l'obiettivo di distribuire al meglio i flussi condensati che possono manifestarsi nelle ore di punta.

Nella prima parte del documento viene presentata un'introduzione sul “gigantismo navale” ed è integrata con lo stato dell'arte della letteratura su questo argomento. Subito dopo viene presentata una presentazione del software utilizzato AIMSUN, ovvero un software di simulazione del traffico che ha aiutato a modellare e determinare le condizioni dei diversi scenari. Successivamente è stata fatta una presentazione del caso studio, dando una breve contestualizzazione sulle caratteristiche della città e del porto. L'ultima parte presenta la descrizione, i risultati e la discussione dei quattro scenari, terminando con le conclusioni.

Abstract

En este trabajo de Tesis de Maestría el objetivo es identificar los efectos que tendría la implementación de Sistemas de Transporte de Inteligencia (ITS) para resolver problemas de congestión, tales como los largos tiempos de espera, la saturación y la disminución del rendimiento del sistema. La tesis se centra en las preocupantes consecuencias en el entorno de los terminales marítimos que está provocando el gigantismo de los porta-containers que en los últimos años ha tenido una evolución desproporcionada.

El objetivo es generar una perspectiva general de la situación y una posible solución; no obstante, el estudio se centró en el Puerto de Trieste como medio para desarrollar el caso de estudio teniendo en cuenta que es uno de los puertos más relevantes y en crecimiento de Italia y toda la zona mediterránea. Se generaron tres escenarios con el fin de describir la situación actual de las condiciones del tráfico y un escenario esquematizando la posible solución, este se sugirió pensando en desarrollar una serie de estrategias de gestión del tráfico presentando un sistema de difusión local que permita al puerto compartir *traffic information events* y tiempos de viaje, con el objetivo de distribuir de mejor manera los flujos condensados que puedan aparecer en las horas pico.

En la primera parte del documento se presenta una introducción sobre el “gigantismo naval” y se complementa con el estado del arte en la literatura sobre este tema. Después, se presenta una presentación del software utilizado AIMSUN, que es un software de simulación de tráfico que ayudó a modelar y determinar las condiciones de los diferentes escenarios. Luego se realizó una presentación del caso de estudio, dando una breve contextualización sobre la ciudad y las características del puerto. La última parte presenta la descripción, resultados y discusión de los cuatro escenarios; terminando con las conclusiones.

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1. Introduction

First of all, it has to be emphasized that economic activities are strongly linked to the variation of the demand transport network. Thus, through the years, when the economy grows, a transport network increase is also observed. However, as one of the goals of the European Union is to protect the environment and make it compatible with the economic development, the European transport policy is now moving forward to maritime intermodal transport solutions since the most ecological transport mode is this one (Novo-Corti and González-Laxe, 2009).

In this order of ideas, five main topics related to freight transportation, focusing on maritime and intermodal modes, will be addressed. The state of the art, for each matter, will inspect the problem and the current methodologies used to solve or treat them and their impacts or contribution to the transportation systems. The five subjects to be treated are: traffic peaks due to ship arrivals, inland traffic, movement and traffic management, the role of Intelligent Transport Systems (ITS) making a detailed review on the FENIX project, and the fifth one, the impact assessment.

In order to carry out the simulation and respective analyses, Trieste was chosen as a reference case, doing deep research on its structure and its Port's performance. The idea is to execute an objective model to understand what is happening worldwide in the port cities. With this aim, Trieste's municipality was contacted as a support entity, being of outstanding help for the data acquisition and the model development. The engineer Fabio Lamanna was the direct contact with the city hall providing a complete study of the Trieste traffic. This study was composed of zoning done by individuating 79 zones based on each quarter's attraction and generation activities. It was also provided a fulfilled matrix for light vehicles and another for heavy-duty vehicles indicating the trips done between one zone another; this matrix is called an origin/destiny matrix. The study was run in the spring of 2019 by the peak morning hour.

Considering that the study was done only in a specific zone of Trieste, only one part of the matrix was considered doing a re-zoning adapted to this case study. Therefore, the description of the adapted study will be explained previous the explanation of the scenarios aiming to clarify the new study context.

The Regulation Plan of Trieste's Port done by the Port's Authorities was also consulted, where it was possible to overview the port situation and forthcoming. This document was essential to understand the base conditions of the traffic, having reported the TGM of different segments of the studied motorway, the most representative for the port's inland activities. This data was taken as a reference to verify the compliance of the given traffic study and the developed model with the actual conditions. This document also reported a consistent description of the importation and exportation activities done by section, which helps us understand the volume of transit present in the case study port's zones.

2. State of art

2.1. Traffic peaks due to ship arrivals

The containerization process has increased drastically, being promoted, as said before, by globalization and economic development, turning this sector into the one that has had the fastest growth in this industry during the past two decades. Looking back into the 2000s, there is a significant engrossment of freight in main ports, especially in Ireland, France, Italy, Portugal, and the United Kingdom (Novo-Corti and González-Laxe, 2009). However, as exposed by Ebeling (2009), the world's trade goods are primarily transported in containers, with a percentage around 90% of the total world's freight, as larger container vessels generally bear lower-cost units and due to the scale economies models, shipping liners set up larger sized container vessels. This situation carries us to a problem because when a large container vessel arrives, the terminal needs to manage a vast quantity of containers within a short time window what brings into high capital investments and maintenance costs.

In order to inquire into productivity and efficiencies of container vessel under the previous behavior and assuming that this trend will run in the future, a group of experts of the National University of Singapore and Shanghai Maritime University carried out a study to evidence the impacts of these kinds of conditions, bottlenecks at the ongoing container terminals and the turnaround time. Their literature review was based on three general axes. The first one focused on planning and developing the container terminals, checking container terminal studies, layout planning, implementation of information systems, and the automation of transport trucks. The second category was concerned with the solution of problems associated with container terminal operations, for example, the berth and the quay crane allocation problem, human resource scheduling problems, strategies for stacking containers and for using yard cranes, and the rules for dispatching transport trucks using optimization models. Finally, the third and last category reviewed different case studies linking the theories and the practical applications (Qiang Meng et al., 2016).

As Qiang Meng et al. (2016) expressed, simulation has been used to look better and analyze container terminal operation processes, due to, as known, analytical methods are hardly creditable for solving complex, large-scale problems. The queuing network model has been used to skim through container terminal operations for decades; different setups of this model type have been implemented over time. Liu et al. (2002) also conclude that the Automated Guidance Vehicles (AGV) system carries out the best between other design concepts. Qiang Meng et al. (2016) survey a case study in the Port of Naples that concludes that automated terminal equipment can increase a port's throughput and reduce handling costs. Nevertheless, they concert that by that time, little work had been done to audit the impact in the container terminal operations by using an efficient simulation approach, and that is why they develop a queuing network model to capture all essential operational processes in a container terminal and proposes a simulation tool to implement the model.

The queuing model developed by Qiang Meng et al. (2016) follows a scheme using a network of queues consisting of several interconnected queues, as it is going to be shown.

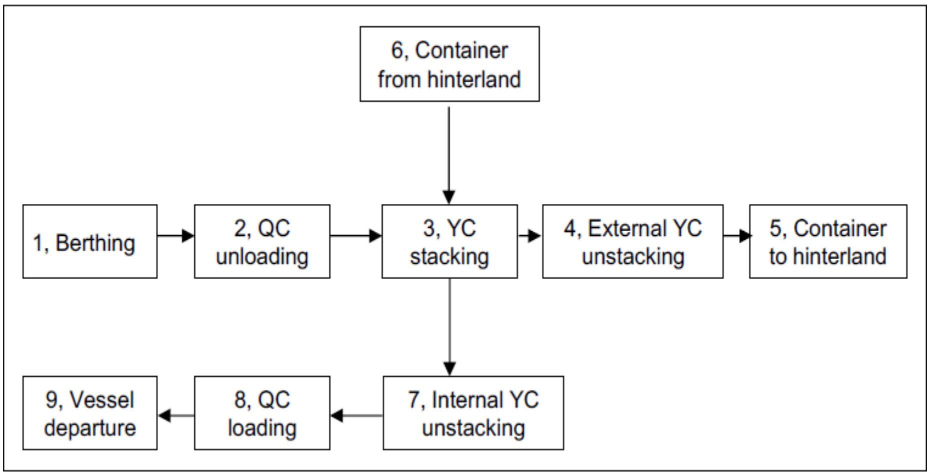


Figure 1. Scheme of the interconnected queues (Qiang Meng et al., 2016)

For each queue, they defined the essential elements such as name, customers, servers, the arrival rate of customers, service rate of servers, and a priority rule. It is also important to highlight that for each queue, major assumptions must have done, principally regarding the arrival and service rates. The following table will expose which kind of distribution they use, considering the most appropriate ones given the characteristics and conditions of the flow.

Table 1. Summary of arrival and services rates, Qian Meng et al. (2016)

QUEUE NUMBER	CHARACTERISTICS
1- Berthing	Vessel's arrival rate: Poisson distribution, also exponential if traffic of whole port is considered. Service rate: Triangular distribution. Customer's arrival rate: Poisson distribution.
2- QC unloading	Service rate of a quay crane: Triangular distribution.
3- YC stacking	They take into account three kind of yard containers: 1- Containers unloaded from a vessel that are going to be carried to port's hinterland 2- Containers unloaded from a vessel to be loaded to another vessel 3- Containers originating from the hinterland to be exported. It is important to know that the first two are going to be transported for internal trucks while the other is going to be transported for external trucks. Arrival rate: It will depend on the truck's travelling time and outputs of Q2 and Q6. Service rate: Triangular distribution.
4- External YC unstacking	Arrival rate: Poisson distribution. Service rate: Triangular distribution.
5- Transporting containers to hinterland	Arrival rate: Depends on the Q4. Service rate: Triangular distribution.

6- Containers transported from hinterland	Arrival rate: Poisson distribution. Services rate: Triangular distribution.
7- Internal YC unstacking	Arrival rate: YCs are going to serve only when internal trucks arrive. Service rate: Triangular distributed.
8- QC loading	Arrival rate: Depends on output of Q7. Service rate: Triangular distribution.
9- Vessel departing	Once unloading tasks have been completed for a vessel, it will depart from the port. Arrival rate: Will depend on the outputs of all the previous queues. Service rate: Triangular distribution.

It has been considered essential to summarize the arrivals and services rates to have a base of the suitable distributions for future modeling. In the model used by Qiang Meng et al. (2016), realistic container terminal operations have been represented, avoiding making strong assumptions, consisting of several logical constraints, policies, and rules. The software used by them was ARENA © that is a qualified software, as Shyshou et al. (2010) expressed to use in the modeling of queuing network simulation employed recently in the study of an offshore anchor handling fleet sizing problem. This software is suitable because it can be handily set with the built-in process module and the required programming skills are minimal. In the following scheme is presented the main level of simulation model used by Qian Meng et al.

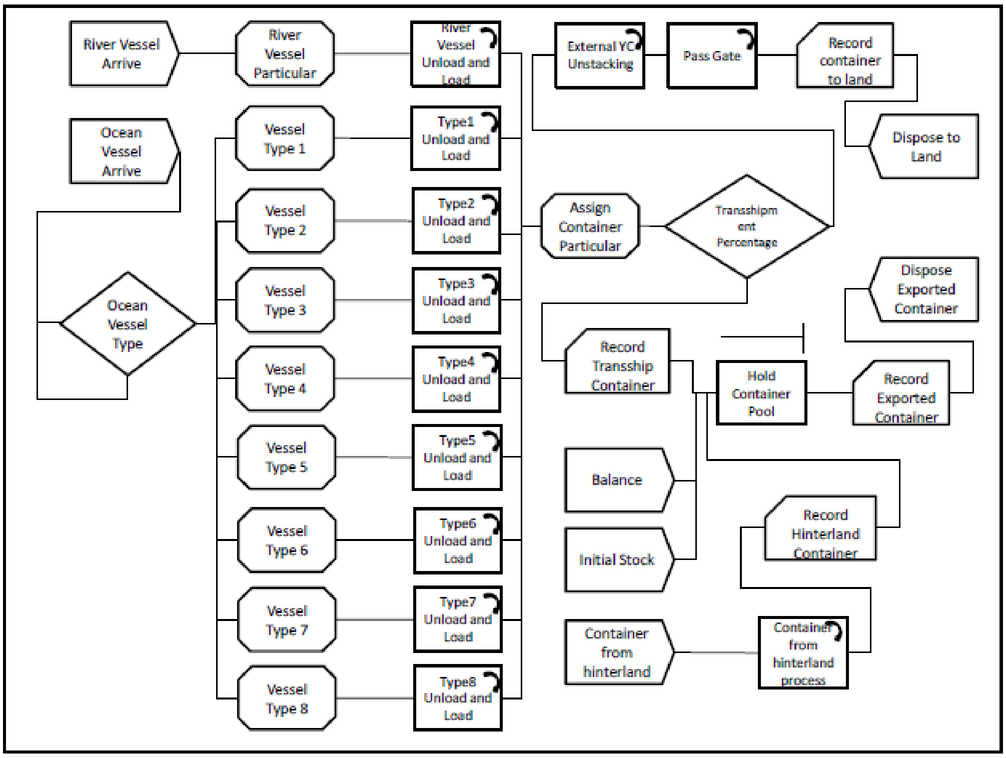


Figure 2. ARENA main level of simulation model used by Qian Meng et al. (2016)

Dachyar (2012) also propones the stepping of his modelling used in his investigation about the simulation and optimization of Services at Port in Indonesia.

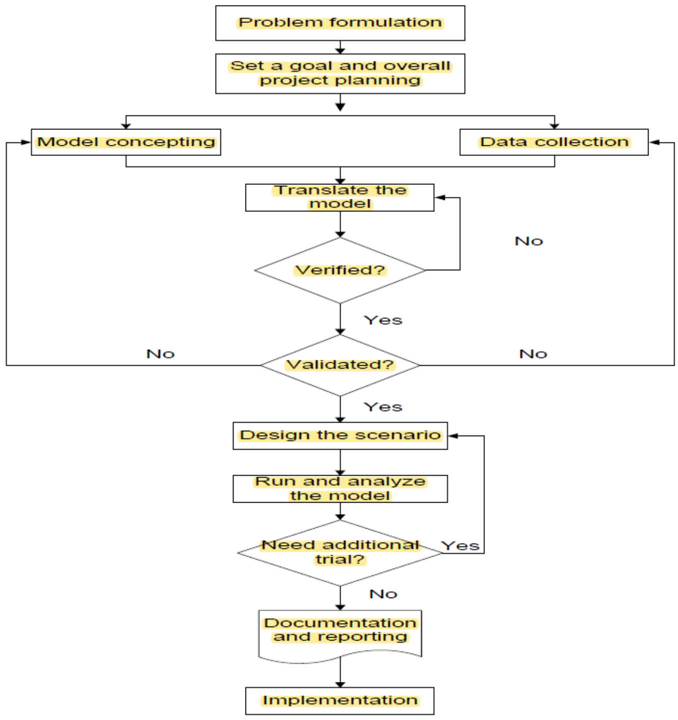


Figure 3. Step of simulation made by Dachyar (2012)

The data collection was done through the company's historical data, direct observation of the locations and the flow of passengers and vehicles, and time study to calculate the time of each process. He instead used the software ProModel to make the computer simulation, considering the system's behavior and the effects of the addition of the ship, dock, or ship schedule changes. Scenarios are developed based on the seasonal wave conditions, the number of docks, the number of ships, and the headway of ships (Dachyar, 2012).

It is important to emphasize that because these models are stochastics, the simulated results are not equal, so to minimize the errors and get consistent results, various simulations must be done. The theory of probability and statistics will determine the number of required runs. The simulation results for this case indicated that if more mega container vessels are used, the performance keeps increasing. However, it must also consider the capacity of the port and the available current equipment because more mega vessels are traduced into a significant investment. Although, as also shown by Matteo Ignaccolo et al. (2020), nowadays, in many cases, it is necessary to improve the capacity of port terminals to amplify its performance, as the case studied by them, in the port of Catania, a new area of the port has been constructed in order to host the increasing number of semitrailers serving Ro-Ro traffic, the peak flow in the ships traffic induces to several consequences not only in the port zone but also in the surrounding areas. In the case of the second largest city of Sicily, the mix of urban and port functions activities is of the main critically, with overlapping traffic flows of heavy and private vehicles and non-motorized mobility, causing many negative factors (Ignaccolo et al., 2020).

For this context, the use of intelligent transport systems, to be treated later, can constitute an essential resource to the collection of data serving as a proper support to diagnose the proper actions to be adopted by implementing the right policies and measures or the adequate management measures (Ignaccolo et al., 2020).

To summarize, the aim was to briefly look into the phenomena that have caused the increase of maritime freight transportation use, the problems or consequences that this may generate in the port's management and function, and its surrounding areas. Second, it has been done a special retrospection of the article of Qiang Meng et al. that gives a detailed description of a model solution for mega vessel's flow issues. Third, it has been exposed the scheme of two different simulations that may be useful in forwarding modeling processes. Finally, it was provided a concise overview of a case study in Catania's Port that evidences the external sequels of non-balance port management.

2.2. Inland traffic

As expressed in the previous chapter, container terminals had gained a lot of importance in the freight transportation sector, they play the role of exchange hubs in intermodal transportation, offering the transfer facilities to move the merch from the vessels to trucks, trains and barge or vice versa. That is why the inland traffic is so important, because given the high concurrence container terminals are always competing as being chosen as global supply chains and the connection with the hinterland has converted in a really important factor in this competition, fast service is traduced in strong competitive advantage (Zehendner and Feillet, 2014).

In this order of ideas, the optimization of inland traffic is now a key factor, because if the peak of the truck arrivals match with the heavy workload time windows for the vessels, barges or trains the service quality and performance level of the entire terminal could have a decrement. Zehendner and Feillet (2014) sustain that, previous studies in this topic have a local perspective neglecting the fact that internal material handling resources serving trucks. Nowadays, some terminals make the use of the appointment system mandatory, others work with and without appointment, it is the terminal who must decide whether to offer appointments on a container or on a truck basis. They found out that many case studies had confirmed that appointment systems have the potential to reduce congestion within the terminal.

Considering the previous information, Zehendner and Feillet (2014) proposed a truck appointment system to reduce truck turnaround times, increasing not only the quality of trucks, but also of trains, barges and vessels. They used a mixed integer linear programming model to calculate the number of appointments to offer a proper capacity respecting to overall workload and available conditions. The used model is based on a network flow representation of the terminal and its objective is to minimize each one and the total delays presenting in the scenario, determining at the same time the number of truck appointments to manage the different transport modes.

They choose a mandatory appointment system, where trucks must book an appointment for a specific container, giving in this way the duty to the terminal operator to determine how many drivers are needed for the next day, as said before one of the objectives is to determine an accommodation that minimizes truck deviations and delays of trains, barges and vessels. But in the model made it, the big scope was to create a model generic enough to be easily adapted to different services strategies and delay criteria, each vehicle is described by its arrival time, its due date and the number of tasks, in the other, the handling capacity is limited by the number of available staddle carriers and their average handling capacity. It is important to highlight that it had been run a few scenarios with different set values to carry a proper optimization model. And to analyze the results, it has been compared a terminal with this model against to a terminal without it, finding that less truck delays occur for the terminals that implement the appointment system. The simulation was done using ARENA 11 and even though the analysis done, relies on a limited number of numerical experiments, the results promise that they could be generalized (Zehendner and Feillet, 2014).

In the other hand, we have that long truck queues at gates often limit the efficiency of a container terminal, generating also serious air pollution. Chen et al. (2013) developed a method that tries to reduce the gate congestion, this one is called Vessel Dependent Time Windows (VDTWs), its objective is to control truck arrivals assigning different time windows to each group of incoming trucks. This method is based in a three-step configuration:

1. Predicting truck arrivals based on the time window assignment
2. Estimating the queue length of trucks, using a non-stationary model
3. Optimizing the arrangement of time windows to minimize the costs (Truck waiting time, idling fuel consumption, cargo storage time and storage yard fee)

The methodology used by Chen et al. (2013) is shown in the following scheme:

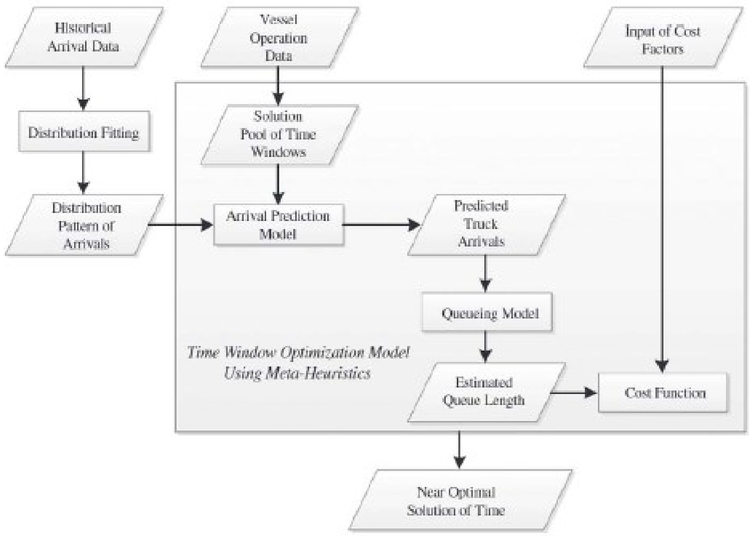


Figure 4. Procedure for optimizing time windows for truck arrival management (Chan et al., 2013)

It has been concluded that, this method can flatten traffic demand, reduce truck/driver waiting time hencing the air pollution and finally the terminal in question can use the storage space by virtue of shorter export container storage time (Chen et al., 2013).

Broadly speaking, queue reduction can be achieved by expanding the gate that implies investments, finding solutions as the one proposed by Dekker et al. (2010), the concept of exchange terminal (CET). The basic idea was to build an outside container storage yard to alleviate congested terminal, in this space truckers can drop off and pick up containers when the peak times occurs, increasing gate capacity and spreading some peak traffic to off-peak times. In rather, we have truck arrival management (TAM), between which we can find the previous model propose by Zehendner and Feillet or VDTWs, TAM is a relatively new topic in the container terminal research.

The aim of this chapter was to give a brief explanation of the problem present in terminals by inland traffic, describing the importance of it in the concurrence of container terminals, exposing the models used nowadays for its solution and in some general features shows the methodology implemented in order to carry on these models.

2.3. Movement and traffic management

Because of the increasing demand and the importance developed by container terminals, the movement and traffic management had become an essential subject in the field of freight transportation. Each day, since the container shipping industry appeared on large scale in the 60's, it has improved its performance at an incredible pace. Because of this reason often it is searched to develop new strategies to keep improving the throughput in order to satisfy the new demand. Port capacity can be increased by physically expanding the already available ones or there are other options such as adding conventional equipment or improving the productivity using new technologies, work organization or application of Intelligent Transport System as is going to be treated in the next chapter (Roso et al., 2009).

Roso et al. (2009) stand that the problems related to the increasing container flows are best handled from a joint seaport and hinterland perspective. So, it is said that a proper use of dryport concept may help to identify ways of shifting freight volumes from road to more energy efficient traffic modes that are less harmful to the environment, relieving some congestion from port cities making the whole system more efficient and facilitating the improvement of logistic solutions for shippers in the port's hinterland.

But what a dry port is? As expressed by Roso et al. (2009), the dry port is a concept based on a seaport connected by rail with inland intermodal terminals where containers can be dealt with the same way as if they were in a seaport, it is basically an inland terminal which is directly linked to a maritime port. It can be distinguished three kind of dry port: distant, midrange dry and close ones.

Distant dry ports are the most conventional ones, it is implemented because the distance and the size of the flow make rail viable from a strict cost-perspective. It is a fact that one train can perfectly substitute 35 lorries in Europe and more than 100 lorries in USA, reducing external effects in the journey. The principal reason why it is used a distant dry port is that a wider hinterland can be secured by offering shippers low cost and high-quality services. This the option that most benefits railway's operators and decreases the environmental impact on the industry, decreasing also high traffic in the street of port cities creating a better quality of life for the citizens (Roso et al., 2009).

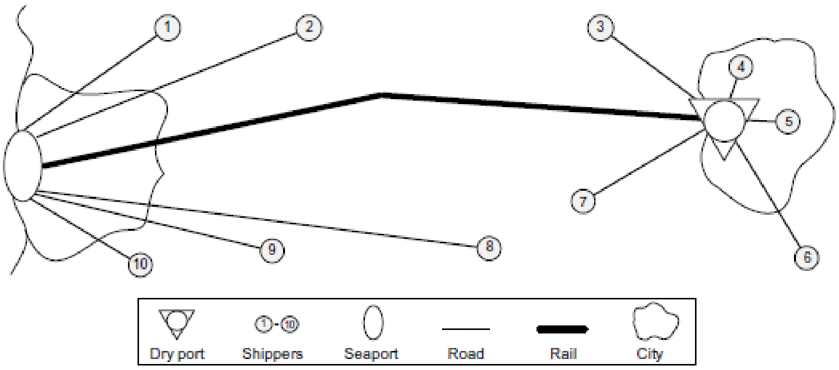


Figure 5. Distant dry port scheme (Roso et al., 2009)

A midrange dry port is then defined as an inland terminal situated within a distance from the port generally covered by road transport, serving as a consolidation point for different rail services, the benefits are similar to the distant dry ports, in figure 6 is shown the midrange seaport (Roso et al., 2009).

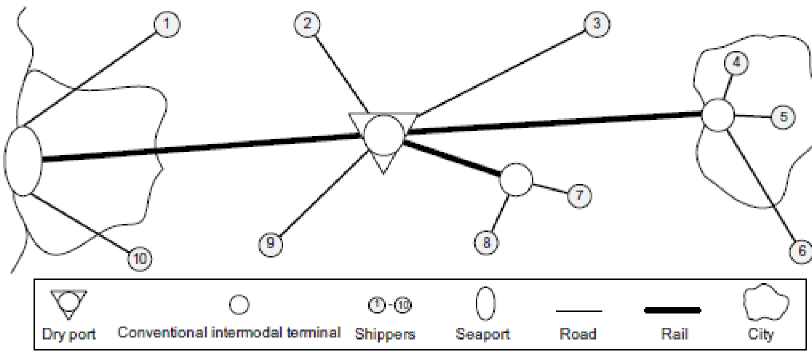


Figure 6. Midrange dry port (Roso et al., 2009)

Close dry ports consolidate road transport to and from shippers outside the city area offering a rail shuttle service to the port relieving the city streets and the port gates. Making a comparison between this one and the other kind of dry ports, this one offers many more possibilities for buffering containers and even loading them on the rail shuttle having a synchronism with the loading of a ship in the port (Roso et al., 2009).

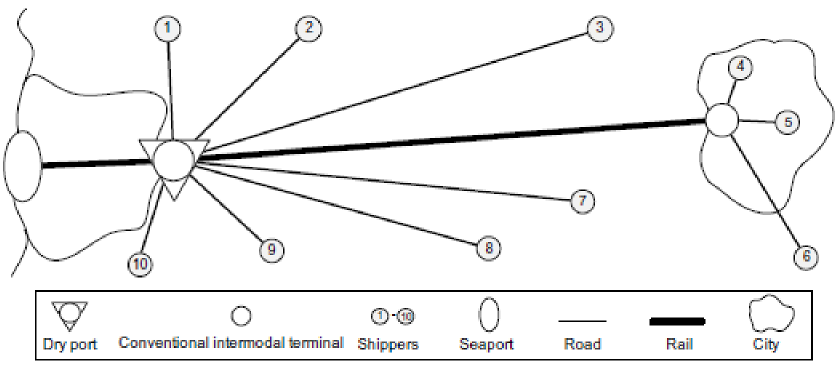


Figure 7. Close dry ports (Roso et al., 2009)

In conclusion, besides the clear environmental and ecological benefits and the improving of citizens life quality, dry ports offer to the seaport the possibility of securing a market in the hinterland, increasing the performance without making an actual physical port expansion as well as the offer of better services to shippers and transport operators (Roso et al., 2009).

In the other hand, Dekker, Van der Heide, Van Asperen and Ypsilantis (2013) exposed the Chassis Exchange Terminal (CET) as a solution for truck congestion in container terminals, addressing some problems that are present in the transport of containers with trucks such as the low utilization of the terminal during nights and weekends, road-congestion, high turnaround times and equipment failure. We already have briefly exposed this concept in the previous chapter but now we expand the concept to know more a detail how it can be used to manage traffic and movement. A CET works basically under the following idea

> During the night containers are collected from these container terminals using chassis (or trailers). In daytime these containers on chassis are the collected and exchanged with export containers also on chassis. By exchanging the chassis, we avoid extra handling of containers. As connecting and disconnecting to a chassis can be done in a short time, the chassis exchange terminal increases handling capacity substantially during peak hours (Dekker et al., 2013)

Nowadays, even though European legislation is trying to increase the rail and barge market, it has also been recognized that enforcing the wanted modal-shift will take time, so that is why the optimization with the existing modalities is now used as the best way for achieving the desired logistic system (optimal and sustainable). It is clear that the turnaround time increases when the truck has to go around the terminal or move from one terminal to another to deliver the merch. CET will use the off-peak timing to transport containers from and to seaport terminals, based on: A stacking method, "Stack on wheels", where containers are placed directly on a chassis at the terminal, and shared chassis pool (Dekker et al., 2013)

CET has basically two processes:

- Chassis exchange: truckers deliver a chassis with an export container and collect a chassis with an import container.
- Shuttle service between CET and seaport terminals: Off-peak shuttle service to transfer containers to the seaport terminals and vice versa (Dekker et al., 2013).

CET has many advantages, Dekker et al. (2013) list further advantages that may have the parties involved, such as the increment in daily number of trips, less empty trips and increase of workload in off-peak hours for seaport terminals and broadly it will reduce greenhouse gas emissions. Even though the development of CET requires a piece of land and investment like the preparation of terrain, automated gates system and the entrance and exit, office building for personnel and IT hardware and software for terminal operations; in general, these investments are very less compared to other solutions, for example train or barge terminals.

Summarizing, in this chapter the idea was to emphasize the problems already exposed by the increment of container terminal use and exposing two different solutions that are in the actuality used to handle and manage the movement and traffic problems. Dry ports and CET have been exposed and described, also enlisting some of the advantages providing by them.

2.4. Traffic congestion problems in port cities

As explained in the previous chapters, one of the most rapid growing segments when we speak about global shipping industry is the containers; most of the countries have developed a growth in this sector and it can be seen hundreds of cases of this industry increment. The United States for example, according with Drewry (2009), in recent years has had around 10% - 11% growth rates per year in this sector; this trend has caused one of the most critical issues, congestion (Transportation Research Board Executive Committee, 2006). Fan L., Wilson W. and Dahl B. (2012) quoting Shrank and Lomax (2004), indicate that "congestion has growth everywhere in areas of all sizes. Congestion occurs during longer portions of the day and delays more travelers and goods than ever before".

The consequence of this problem is reflected into the costs, inter-port competition and other logistics functions. Ports all around United States, for example, were not ready for the massive wave of imports that started in 2004 and continued in the following years, this congestion in the ports rapidly spread into the supply chain affecting the rail lines, freeways, and warehouses.

In the article written by Fan et. al. (2012), had been enlisted some recent studies where have been analyzed the impacts of railways capacity, port efficiency, containers, and logistics. Between the studies named by them, it can be found some interesting works related to inland traffic; De Borger and De Bruyne (2011) examined the effects of vertical integration between port activities and hinterland congestion. Cambridge Systematics, Inc. (2007) estimate current and long-term capacity expansion of freight railroads and the role of congestion among corridors in the US. Crainic and Kim (2007) treated the interpretation in the context of network flow models of intermodal transportation, arguing that delays often occur at US ports and inland networks connecting port facilities. The port throughput capacity is drained by bottlenecks at multiple port's sections used for unloading/loading, storage, and transfer.

This is a phenomenon that is involving the whole world, Doctor Usman Gidado (2015) studied the consequences of port congestion on logistics and supply chain in African Ports, studying cities like Durban, Lagos, Mombasa and Port Said. He sustains that this event is strongly associated with delays, queuing, extra rime of voyage, dwell of ships and cargo at the port that ends in consequences on logistics and the supply chain that it can be translated into extra costs, loss of trade and a disruption of commerce and transport agreements. Longer transport times reduce, inevitably, the trading and increase the cost of the products causing a decrement in the compressive value of the product. Africa, for example, estimates a deficit of 48 million of dollars per year.

Even though containerization has improved the efficiency and has intensified the competition among the gateway seaports, the competition is not anymore related only to the individual ports but between the number of alternate intermodal chains. The inland leg has got more attention from industry investors, government, and academia because it costs around 40% to 80 % of total container shipping costs. It has been cleared, Seaports with more hinterland transport infrastructures are more likely to overcome the newly established trade flow market (Yulai Wan, Anming Zhang and Andrew C.L. Yuen, 2013).

Yulai Wan et. al. (2013) sustains that a 1% increase in traffic congestion is directly associated with 0.9 – 2.48% reduction in the container throughput of the affiliated seaport of that urban area. Adding road capacity is considered one of the most common and important road congestion mitigation strategies but it has different implications on container throughput. Having as example the positive correlation that has this intervention with the Port of NYNJ, LALB and the Port of Miami but the negative effect that this had in the other port investigated by them, that is why local governments and port management must be careful when they decide to provide more roads because it might be harmful to the port's outturn overall, even though beneficial in terms of mitigating road congestion (Yulai Wan, Anming Zhang and Andrew C.L. Yuen, 2013).

Since the increment of arrivals in the port due to the explosion of container industry, many port cities have had to deal with the consequences in the urban traffic. In Italy, as in mentioned before for US, cities were not ready for the massive wave of import and exports. The Adriaeco reports that La spezia experiment infinite queue, eternal waiting times, lacking coordination and the impossibility of schedule trips and deliveries. The Community Portuale Spezina expressed their desperation asking to the Port authorities to developed new strategies in order to control the chaos that has come with the arrivals of the ships. In 2017, Sergio Landolfi had expressed the willing of create a functional alliance that allows a rationalization of traffic flows to and from the port, a reduction in pollution and the recovery of human working conditions for road hauliers " (Adriaeco, 2017).

Notwithstanding the efforts, two years after Città della Spezia (2019) expresses that the problem was not solved but moved. The heavy traffic that in the past years blocked the entrances in the Stagnoni in 2019 was concentrated in Santo Stefano Magra. The queues of heavy vehicles reach up to the motorway junction creating an evident danger for motorists, exactly as it used to happen in via Carducci.

Figure 8. Urban traffic generated by the port of La Spezia (Città della Spezia, 2019).

Genova, another Italian port city, for example, has also lived the consequences of the excessive freight transit. GenovaToday (2020) reported dozens of heavy vehicles headed to the port forming a very long queue along the Guido Rossa, also blocking the roundabout in via San Giovanni d'Acri, the greatest problems were recorded in this roundabout, at the entrance to the Guido Rossa, due to the "lack of absorption of the port road network", as also explained by the local police: traffic is congested », they confirmed mid-morning from the local switchboard. The long line of heavy vehicles headed (and blocked) at the port gates inevitably had repercussions on the entire road network, with exasperated truckers and motorists.

Figure 9. Genova traffic due to ship arrivals (Genova Today, 2020)

2.5. Role of ITS in-freight transportation

To begin it is important to define what Intelligent Transportation Systems are, as defined by the European Union (2010), they are a group of advanced applications that allows to provide innovative services relating to different modes of transport and traffic management, to make users to be informed and make safer, more coordinated, and smarter use of transportation networks. They integrate telecommunications, electronics, and information technologies with transport engineering with the aim to plan, design, operate, maintain, and manage transport systems. In this case, we will focus more on the role and application of ITS for the case of freight transportation, as expressed by Oskarbski and Kaszubowski (2016), the nowadays trends in shipping transportation are to show a high potential in their utilization as the way for more sustainable goods transport, of course with the introduction of advanced transport technologies.

Between the solutions exposed by them it can be found traffic management systems, access rights for different vehicle classes and traffic conditions, provision of open traffic information for accurate vehicle routing and loading areas surveillance or vehicle monitoring. They argue that it should be considered important, as a policy measure, the modelling of traffic flows since it plays an important paper when to improve efficiency comes, between the simulation models that they consider for their paper it can be found models of vehicle routing and scheduling, multi objective optimization, intelligent agents, system dynamics, multi-agent systems and game theory and traffic simulations.

The available data also plays a crucial role because it influences the urban freight planning and the implementation of ITS systems. That is why it is imperative identify the main types of freight flows present in different configurations for each environment. Browne et al. (2007) defines the main groups of freight movements for urban areas as: Shipments of goods into an area to be consumed within that area, shipments out of an area of goods produced in that area, intra urban collection and delivery and local shipment where the vehicle has its origin and destination within the same area and finally transient movements – goods passing through the area directly and goods undergoing temporary storage. The required data for each modelling process may variates depending on the aim of itself, nevertheless the following factors has an important part into ITS performance and implementation (Oskarbski and Kaszubowski, 2016):

- Total number of goods and service vehicle trips
- Total number of goods and service operating vehicles
- Average trip length of goods/service vehicles
- Fossil fuel consumptions rate of goods and service vehicles
- Size and weight of vehicle used
- Number of goods and service vehicles parked on -street at peak hours
- Period for average delivery or service trip
- Time of goods and service vehicle operation
- Average travel speed within specified area

Other factors as public or private information, socio-economic data, spatial management data and the dynamic fluctuation of transport needs must be as well considered.

Models as four steps models for passenger traffic may be very useful in the modellation of freight problematics in consideration that it can be use in some categories such as e-commerce or express courier making an analogy to passenger travel, allowing the counting of number of trips generated in the given transport area and then deduces an origin- destination matrix of the merch. Regarding to other kind of problems, it can be considered another category of models generating freight traffic that contemplates trip chains or rounds, describing concurrently trip distribution between transport zones or designated places in the network. ITS technologies play a vital role in modelling, relying on intelligent agent software or the multi agent's method, furnishing options in the tracking vehicles task and locating them in time and space allowing the prediction of its behavior.

Oskarbski and Kaszubowski (2016) sustain that ITS are key enablers to reach the objectives of public policies regarding to transport activity, benefits from its use can be describe as a response to the issues related to urban freight integrating the private sector and public sector. They hold that private sector may be promoted by making itself more efficient and productive, as well as reliable with its services, listing the factors that can help to achieve the gains such as better management of people and equipment, reduction of non-productive waiting time, better schedule adherence, operational flexibility and reduction of errors and order processing times, summarizing all the benefits in the following figure.

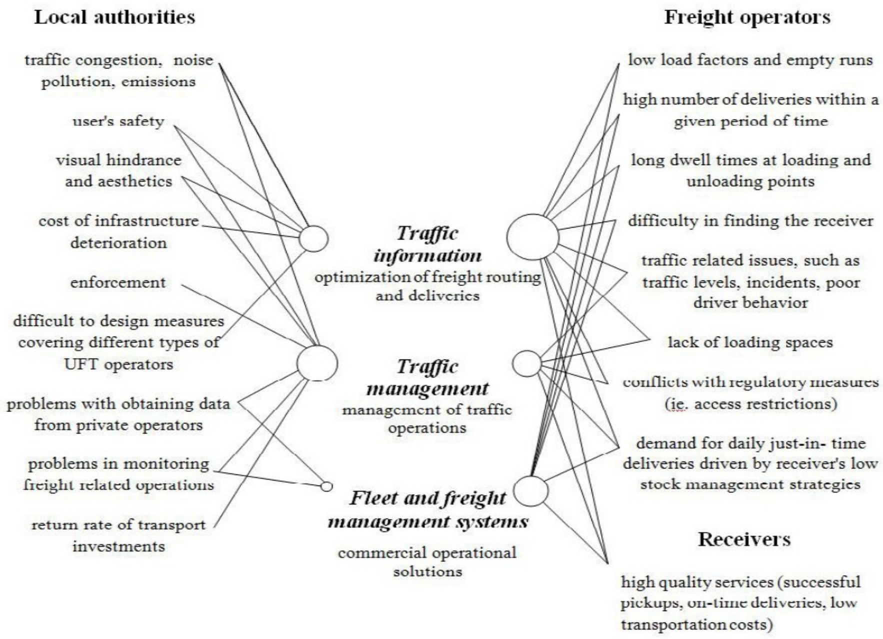


Figure 10. ITS Contribution to addressing of urban freight stakeholders concerns (Oskarbski and Kaszubowski, 2016)

Nonetheless, the real usefulness will depend on the accessibility or earlier specified data, and what is even more important being acknowledge of how to apply them, without this the ITS solution may fail to find justification (Oskarbski and Kaszubowski, 2016).

In a case of study in Gdynia, it was found that the use of vanguard technologies can increase the operational area of traffic management and can also support the planning and design of transport systems solutions for the current traffic disposition. In this city, constituting the triple city capital of the Pomeranian Voivodeship, the objective with the use of ITS was to improve the traffic conditions by providing traffic management tools and to increase the share of public transport by improving its competitiveness thanks to the use of ITS technologies. For example, it was found that dynamic vehicle routing with real time information and scheduling and parking guidance system for freight vehicles are highly recommended measures in terms of required time and effort taking into account the requirements of the problematic of this city or that multilevel transport system model may be an important tool supporting planning and evaluation of urban freight measures. As a outcome, it was concluded that the ITS solutions by them presented can be considered as a interspersed part of the planning and implementation of urban freight management measures making an important contribution to the results in each of the three application groups of shipping transportations, which are: Optimization of freight flows, reduction of demand for freight services and transfer of operations to sustainable modes of transport (Oskarbski and Kaszubowski, 2016).

Małecki et al. (2014) studied the influence of ITS on reduction of the environmental negative impact of urban freight transport based on Szczecin example, trying to analyze the influence of the system in the task of reducing the adverse impacts or urban merch transport on the city. The tesis was that due to the effectiveness of the transport management and traffic flows control it is possible to reduce congestion and shorten the completion times of transport tasks. This responds in a reduction of petrol's consumption and therefore less pollution. In Szczecin, the main problem was regarding to pollution, given by the city's geographical location (connection with big cities as Berlin, Prague and Budapest) and its importance as a maritime industry. The major goal of implementing a traffic management system was to create a better flow of the traffic between the roads leading to city center, reducing congestion in the city and thereupon improving the environmental conditions of the city.

As said before the data collection is fundamental to the ITS implementation, in this case the system uses a several range of sensor between where we could find: Video detection to survey and evaluate the traffic conditions over a specified road section with a possibility to specify travel times, laser detection for assessing the raid surface condition, optic detection for adaptive traffic control, among others. The data was processed and the improvement in the traffic flows began with the successful implementation of the traffic management system, drivers were able to choose the better route or alternatives ones to reach their destinations what led to a considerable reduction in the quantity of users travelling through city center, reducing the travel time, avoiding traffic jams and therefore the pollution (Małecki et al., 2014).

Orkarbsi et al. (2006) also exposed that the use of intelligent transport system offers several advantages, between the most important ones can be found:

- Increasing the capacity of the street network by 20 – 25%,
- Improving road traffic safety (decreasing the number of accidents by 40 – 80%),
- Reducing travel times and decreasing energy consumption (by 45 – 70%),
- Improving the quality of the natural environment (reducing pollutants emissions by 30 – 50%),
- Improving the travel comfort and traffic conditions for drivers, collective transport users and pedestrians,
- Reducing the costs of road fleet management,
- Reducing the costs of road surface repair and maintenance
- Increasing the economic benefits in the region

Each day ITS are having a big development implementing new techniques that makes models more like the reality and more efficient measures to regulate and solve the problematics. Nowadays, the concept that has called the attention of the sector is the decentralized intelligence in freight transport, it still presents several challenges but addressed to the smart cargo concept is directed to enable efficient transport planning. Normally Cloud computing is used and it has several advantages as a support infrastructure and large-scale reasoning, but trust decisions and part of control should be led to the edges and being allowed to explore innovative computing applications such as Fog computation. It not only runs latency-sensitive applications at the edge of the network, but also performs latency-tolerant tasks efficiently at powerful computing nodes at the intermediate of network (Costa et al., 2016).

For example:

A smart city with road traffic control, and environmental monitoring over a very large territory is bringing its own deployment complexity. The centralized approach is not sufficient to handle this increasing volume of end devices and its geographical specificities. Data is most relevant, or safest, if it is processed close to the edge of the network (Costa et al., 2016).

A fog architecture could be considered as a network of interconnected intelligent endpoint devices, which conform a connected graph called fog layers, the different layers have different capabilities, in the field of storage, network bandwidth, response time, etc. (Costa et al., 2016).

In the actuality in Europe, as expressed by the official webpage of FENIX Network (2019), it is being developed

> the first European federated architecture for data sharing serving the European logistics community of shippers, logistic service providers, mobility infrastructure providers, cities, and authorities in order to offer interoperability between any individual existing and future platforms.

The main scopes of the European Federated Network of Information eXchange in LogistiX (FENIX) are to establish this network in order to facilitate the sharing of info and services required to the optimization of TEN-T, also prove the operational feasibility and benefits through the organized national pilots-focus and finally set up a EU corridor community building programme and promoting the benefits between the members (FENIX Network, 2019).

In this chapter, the aim was to provide a brief definition of what an ITS means, shows the nowadays trends that are present in the field of freight transportation, it has been presented several applications of ITS and their benefits, two cases of study in two different cities of Poland describing briefly the problematic and how ITS helped into finding the solution. It has been introduced the FENIX Network project and it principal objectives.

2.6. Impact assessment

2.6.1. TRAVEL TIME INFORMATION

As said by Lomax and Schrank (2010) in their study Developing a Total Travel Time Performance Measure, the measurement of transportation performance based in travel time quantities, satisfy non only mobility purpose but a range of them, showing effect on many transportations and land use solutions and they are relatively easy to communicate to different audiences.

There are many different measures that can be implemented to show the effect of mobility problems and solutions on individuals, regions, businesses and economy but one of the performance indicators that has been widely used for muti-modal systems analysis is **Total Travel Time** (Lomax and Schrank, 2010).

In this order of ideas, the Total Travel Time can be defined as the sum of all travel times regardless of mode or travel path, it is also important to highlight that there are two elements in its measurement that should be addressed or recognized before inclusion in a typical mobility performance measures: Insufficient data to estimate all travel by all modes and communication issues (Lomax and Schrank, 2010).

Another key performance index that can be used to measure congestion using the travel time information service is the travel delay, according to Lomax and Schrank (2010) "It is a quantity that indicates where the problems are, what solutions might be and how beneficial the investment will be".

CONDUITS (Coordination of Network Descriptors for Urban Intelligent Transport Systems) (2011) also expose some KPI related to travel time information that can be used in order to measures traffic efficiency in terms of mobility such as Average Travel Time to relevant points of interest, Average Travel Time to relevant points of interest on the public transport network, connection times at transport facilities, Average Commuting Time among others.

2.6.2. TRAFFIC EVENTS INFORMATION

It is clear that a good urban road traffic system is principally given by the efficiency of the passenger travel, being measured in three basic aspects including congestion, mobility and accessibility. In fact, with the rapid growth of car ownership in the last decades, traffic congestion has converted in one of the main problems for urban regions, (Bo et al., 2016).

In the report of the Federal Highway Administration (2005) it is shown that congestion can be basically described as the result of seven principal causes: Physical bottlenecks, traffic incidents, work zones, weather, traffic control devices, special events and fluctuation; all described as internal or external conditions that affects the traffic causing congestion.

Bo et al. (2016) sustain that with the aim of keeping the order of passengers and improving efficiency of the service, it is very important that transit passengers obtain travel information when transit service is interrupted or delayed, the guidance information should give a real-time data of traffic congestion, such as locations and conditions of jams, alternative routes and so on; in the case of public transportation, the bus company should publish real-time bus delayed information and traffic accident information. All of this can be done by the implementation of ITS systems such as GPS surveillance, or SMS actualization messages or if there no SMS, passenger could acquire real-time traffic information in electronic bus stops, among other solutions.

This real-time public information is considered as an individual-specific travel demand management tool. Dziekan et al. (2007) argue that real-time information on the users cannot be ignored,

> They described dynamic at-stop real-time information affects public transport passengers for seven factors: reduced wait time, positive psychological factors, increased willingness-to-pay, adjusted travel behavior. Mode choice effects, higher customer, satisfaction and finally, better image.

In general, Bo et al. (2016) demonstrated in their study that the passengers benefit from the provision of real-time bus arrival information, it means a benefit by the use of ITS. Conduits (2011) provided some recommended KPI to monitor traffic efficiency base on mobility and reliability. As expressed by them

> A mobility KPI can be composed of different elements but essentially consists of the average travel time to different destinations in the highway and public transport networks expressed in time units, normalized by the distance to the destinations, and weighted by importance according to the goals and objectives of the application under consideration (Conduits, 2011).

While a reliability index

> may be composed of different elements related to different modes of transport (e.g. public and private transport). Reliability deals mostly with system efficiency from the perspective of the suppliers who invest most of their efforts in reducing congestion hence providing better mobility (Conduits, 2011).

2.6.3. TRAFFIC MANAGEMENT STRATEGIES

As said before, in the past decades there has been an increment in the car ownership but also and not less important an enlargement of population in the cities, this leads to a need of demand more than the travel facilities can support. Hence, it is necessary to manage the trips in a such way that the traffic can be optimized, and it can be obtained its improvement with the current infrastructure (Moayedfar, 2017).

Moayedfar (2017) in his report quotes the Iranian Transportation Institute and the Secretariat of the Supreme Council for Coordination, the explains that there are two points of view that need to be considered in order to manage it. The first one is to reduce the unnecessary trips, being related to travel demand and the second one is use provided facilities optimally, that it is traduced as how to supply management to make optimum the system.

Traffic management can be described as a modern method used to solve traffic problem, its aim as said before is the optimal use of existing network and road, increasing at the same time the safety, respecting also the environmental rules with benefits in productivity and protecting public profits. There are some ways to solve this problem, but it is observed that the management and monitoring with electronic device such as variable message sign (VMS) is one of the best methods to reduce waste time and traffic congestion (Moayedfar, 2017).

Speed limit and change speed is also an important factor with the time of displaying information in variable message, having that with increasing time period, reaction frequency change from logarithmic to power mode. Variable message sign (VMS) can use changeable message sign (CMS) or dynamic message sign (DMS). It is also exposed that VMS has an especial improvement in accident time (Moayedfar, 2017).

In the same report quoted before, its author details some benefits observed once the whole study was carried on, noting that the sign implemented have an important role in traffic management such as traffic volume, increase efficiency, increase speed, reduced delay and improving the level of satisfaction, it has been summarized some of the benefits reported:

1. Reduce amount of waste time about 100 second per kilometer in this study at 1 hour.

2. Reduce fuel consumption 348 lit per hour in accident time or traffic jam on study route.
3. Reduce density of vehicle by variable message sign and implement strategies on time to reduce traffic volume. Increase satisfaction condition base on reduce waste time.
4. Increase economic productivity, reduce accident burst due to knowledge about front condition and ultimately reduce traffic jam (Moayedfar, 2017)

2.6.4. V2X SERVICES

V2X is defined by Chen et al. (2017) as vehicle-to-everything communications, including vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N), used to improve road safety, traffic efficiency, and the availability of infotainment services. During the journey, V2X applications, that are installed in a vehicle, would monitor the vehicle's state and the activities of the driver. This information is transmitted to the neighborhood, information such as position and speed or dangerous locations on the roadway. V2X applications would whether advise the driver or automatically advise the safety system for the best possible reaction to a dangerous situation (Schünemann, 2011).

In terms of traffic efficiency, how does these applications improve it? Well, they do by exchanging traffic-related information among vehicles and traffic infrastructure units. One example of their functioning is informing the driver about delays to be expected and to optimize the vehicle's speed and route depending on the traffic conditions.

A KPI for traffic efficiency has been presented in the previous service "Traffic events information", but Conduits (2011) also presents several KPI to traffic safety such as Index for traffic accidents, index for applications with a direct safety impact, index for applications with an indirect safety impact in urban environment, index for applications with an indirect safety impact on urban motorways, index for car-to-infrastructure-communication-related applications.

All of the KPI named before are mostly refer to the performance of a respective category of applications, but it is clear that for non-specialized political entities it is needed more general indicators that gives an overview of all systems in a larger area. This is way Conduits also exposes a Total index of traffic safety, that can be defined as a synthetic traffic safety KPI (Counduits, 2011)

2.6.5. FCD AGGREGATION (from mobile app)

Nowadays real time data collection plays a crucial role in traffic engineering for better traffic corridor control and management. In the history many devices and techniques, such as magnetic loops, road tube counters, radar, Bluetooth, among other, have been used as traffic data sources. Recently FCD (Floating Car Data) has been implemented; this traffic source obtained from GPS vehicles that move in the traffic can provide many information such as speed or travel speed data for many segments with 1-min intervals in real-time. Besides, this method has a lower cost and higher coverage; the principle of working is the collection in real-time traffic data that is done by locating the vehicle via mobile phones or GPS over the entire network. This data, that could be car location, speed and direction of travel and they are sent to a central processing center. They process the information with the aim of derive travel time or average speeds through road segments, then detection of congestion/bottleneck locations and finally the determination of traffic flow parameters. This information report of data is then used to later identify the recurrent or not recurrent congestion locations or the bottlenecks, with this information the whole network system can be optimized (Altinasi, 2016).

Studies had tasted the speed profiles generated by using FCD data, against other kind of devices and method such as radar sensors, RTMS data, microwave radar, among others and it has been demonstrated that all data types of speed profile has a similar pattern. So even with just one parameter is still possible to detect critical patterns along urban roads. Observing these patterns variations over time reveal more information about time-varying state of traffic at a precise location or segments, that leads, as said before, to the knowledge of the network and the possibility to the optimization (Altinasi, 2016). FCD are indeed a valuable alternative to roadside measurements, they give the chance to reduce the costs and increase temporal and spatial frequency of speed behavior monitoring, because in theory FCD can be captured at any moment of the day and any location of the network (Diependaele, 2016).

2.6.6. ROUTE ADVICE (from mobile app)

We have previously name and introduce what route advice is, it can be briefly summarized as the basically is the use of ITS to advise or inform the user about the best choice or the events that are happening in the network, this is done with the aim of optimize the network itself. Nuzzolo e Comi (2014) made a research about advanced public transport systems and ITS: New tools for operations control and traveler advising, they sustain that traveler information systems are specialized information systems that are able to access, organize, summarize, process and display information to give as a result shared or individual information.

In this order of ideas, this individual traveler information systems can be distinguished as route guidance tools, trip planners and trip advisors. Route guidance tools give assistances to the traveler during the trip to follow a given path while the other two provide a set of ranked path alternatives generated according to some set criteria. They introduce Advanced Traveler Advisory Tools (ATATs) that use new technologies for the individual real-time information broadcasting, and nowadays with the possibility of offering a better precision and suite in a better way traveler expectation, different ATAT are being tested based on a traveler individual behavior as the presented by the University of Rome, called TVPTA (Nuzzolo e Comi, 2014).

Route advising and special when is providing advance individual information leads to a reduction of waiting time, total travel time and schedule delay. This gives a better performance of the network and a reduction in costs followed by a less impact in the environmental situation (Nuzzolo e Comi, 2014).

2.7. AIMSUN Next Software

Considering the objectives of this thesis, it has been decided to implement Aimsun software to model the traffic conditions. This decision was made giving the flexibility of this program that allows the modeling of both a small network, like a single intersection, and a large one like an entire region.

The applications of this software are infinite, even if we consider the most commons one, we find a great quantity of scenarios and possibilities; it can be done models such as the assessment and optimization of transit signal priority, feasibility studies for high occupancy vehicle and high occupancy toll lanes, evaluation of travel demand management strategies, highway capacity manual analysis or work zone management among others (Aimsun, 2021).

They base their functionality and their reaching in many aspects; as report in the official page the true integration, the user friendliness, the speed, the rich dynamic traffic assignment framework, the connected autonomous vehicles, the openness, the superior software architecture, and the superior version control are some of the axis and advantages offered by this software (Aimsun, 2021).

Aimsun is described as an application that mix the microsimulation, mesoscopic simulation, macroscopic functionalities, travel demand modeling and macro-meso and micro-meso simulators. These skills offer the developing a super large-scale model only making detailed simulation where it is necessary, facilitating the process with low calibration effort and accurate details (Aimsun, 2021).

The previous characteristics allows the definition of areas for microscopic simulation within a mesoscopically simulated network, pedestrian simulation available inside the microscopic areas, demand definition using OD matrices or traffic states, unified statics collection, dynamic traffic assignment based on stochastic route choice or dynamic user equilibrium and traffic management. The four-step modeling is another step that facilitate the true integration, it can be done without being forced to use a different program, not interfacing with external traffic demand models (Aimsun, 2021).

This software is really easy going in terms of friendliness with the user, enables the modeling, simulation and output analysis in a single environment. It is intuitive, giving a highly visual and handy interface. Given the multithreaded software architecture the simulation process is speeded up, independent if it is run on a laptop or a high characteristic computer. As said by them (Aimsun, 2021),

> Even on a laptop, the Aimsun Next microsimulator can run a model of whole Singapore with 10,580 intersections and 4,483km of lanes 2-3 times faster than real time.

The architecture of this program contains a Dynamic User Equilibrium (DUE) techniques and stochastic/discrete route choice models, that can be combined with either mesoscopic or microscopic modeling, offering to the user a incomparable flexibility of modeling with a good level of accuracy. It reuses previously obtained static and dynamic equilibrium assignment routes in news simulation combining them with discrete route choice being able to reproduce the configuration of habitual driving and on-the-fly congestion avoidance that may occur in a real live scenario and giving the possibility of model the operation that impact on the route choice, reproducing a very accurate system behavior (Aimsun, 2021).

2.8. The FENIX project by SWARCO MIZAR s.r.l

SWARCO MIZAR is an international company specialized in telematics systems. Its expertise in different initiatives in traffic management, public transport management, traveler information services, and others has made it become one of the most well-respected companies in Europe. It was founded in 1981 in Turin, and since 2010, after the acquisition by SWARCO, it has developed into a leading company in the field of transport solutions (SWARCO MIZAR s.r.l., 2021).

FENIX, an acronym from Federated Network of Information eXchange in Logistics, is a European initiative that searches to develop the first European federated architecture for data sharing using a digital corridor information system that would serve the European logistics community of shippers, logistics services providers, mobility infrastructure providers, cities, and authorities (FENIX D2.1.1.).

This project is carried out following the execution of different test sites called Pilots all around Europe, each of them provides a detailed description of their planned FENIX activity. The FENIX pilot sites are:

- *Austria*, customs corridor -fürnitz pilot site (south Austria) on the Baltic-Adriatic corridor;
- *Belgium*, Aircargo Pilot Site;
- *Belgium*, multimodal inland hub-Procter & Gamble-Mechelen-Willebroek Pilot Site;
- *France*, French Mediterranean – North Sea Pilot Site;
- *Germany*, Rhine-Alpine corridor;
- *Greece*, Greece Balkan-TEN-T network, Adriatic-Ionian corridor-Cyprus multimodal Pilot Site;
- *Italy*, Trieste Pilot Site: Mediterranean and Baltic-Adriatic and the Motorway of the Sea of South-East;
- *Italy*, Milan/Genova: the Italian Rhine Alpine Pilot Site – Dynamic Synchromodal Logistic Modules;
- *Holland (South Holland)*, Smart Multimodal Pilot Site (LOUVIN);
- *Slovakia*, all TEN-T corridors and multimodal Pilot Site;
- *Spain*, the Spanish-Atlantic Corridor Pilot.

(FENIX D2.1.1.)

This Master thesis is executed under the guidelines of Trieste Pilot site that explores the following Use Cases:

- Expected time of arrival (ETA)
- Reduction of C02 and NOx emission
- Multimodal route planning
- Track and trace vehicle/Shipment
- Dangerous goods/eCall EGNOS/Galileo
- TM 2.0 for multimodality
- Parking booking services
- B2A and A2B services like Customs

The Trieste Pilot site will be a Living Lab covering all the project phases with all the implementing Bodies collaborating in a systematic co-creation approach, with integrated innovation and different research processes (FENIX D2.1.1.)

It will be of our specifical interest the Traffic Management (TM 2.0) concept born in 2011 by SWARCO with the cooperation of TomTom, that rest on both vertical and horizontal collaboration between the different supply chain's stakeholder to achieve long-term competitive advantages in the market. Its main objective is to "facilitate the exchange of data and information between all road users and Traffic Management Centers (FENIX – Derivable 6.2.2).

2.9. Strategy management

Strategic management, as expressed by Anthony Henry in his book Understanding Strategic Management (2008), is the process of bringing about a strategy allowing the organization to match the resources and capabilities to the needs of the external environment with the objective of achieving a competitive advantage. Henty explains that this process is pretty much about analyzing the situation, formulating in base of this different strategies that would be implemented trying always to get the most benefit with the least effort.

Henry (2008) divided the strategic management in three process that are interdependent: Analysis, formulation, and implementation. The strategy analysis, also called situation analysis, is a useful starting point; it involves an examination of the general and competitive environment. In a traffic scenario, it might mean the evaluation of the current strategies that are being used to solve similar problems; evaluate similar cases that might help to understand how the problem could be solved. In this step, it is important to determine the critical sections, the principal performance indicators, important events and analytic conditions.

The strategic formulation is done after a careful analysis that will allow to assess firmly where a strategic can fit the best equilibrium between the need and the external environment. Mintzberg (1994) expresses that the strategy formulation should also occurs as a creative and subconscious action synthesizing the experience forming a novel strategy. Henry (2008) quotes Markides explaining that a effective strategic design is a process where the subject continuously formulates themselves questions, clarifies that is often more important to formulate the right questions than find a solution. In this process is also important to consider the strategy evaluation, where it is recognized that it is always required a criterion in order to judge competing strategies.

Finally, we have the strategy implementation. Strategies must be communicated, understood, and properly coordinated in order to being correctly implemented. In a traffic scenario it might implies the evaluation of the resources and the compliance between strategies aiming the take advantage of all available supplies, using new technologies.

2.9.1. Strategy manager traffic tool – SWARCO

SWARCO defines it as a “strategic tool expressly designed to operate in the framework of integrated Road Traffic Environments (IRTE) where it provides the strategic level coordination among one or more ITS applications deployed to reach mobility management goals”. This tool is designed to help the operators in acting in order to reach the services objectives related to traffic, environment and urban life, allowing the user to:

- Access to a GUI on which strategies are showed and detected.
- Create, update, and delete co-operative operational strategies (scenarios) for all the contributing ITS applications and for all controlled equipment.
- Check the scenarios service level.
- Activate detected strategies in either manual or automatic mode.

The way it works is reacting to monitored service current situation in an organized and dynamic war, to prevent traffic anomaly events or recover from them as fast as possible. Strategies are activated according to the achievements of one of the service levels available in monitored service. It has two ways to activate the strategies: in an automatic way or in a semi-automatic way. Some examples of the controllable actions are:

- Change the status/operating mode on traffic light controller(s)
- Change the plan on traffic light controller(s)
- Change the speed limits on variable speed limit signs
- Change the informative content on variable message signs

There is no limits on the number of strategies to be implemented or configured, and for each strategies there’s no limit of control points and actions. The software is basically composed by three panels: Strategies list, control points and action points.

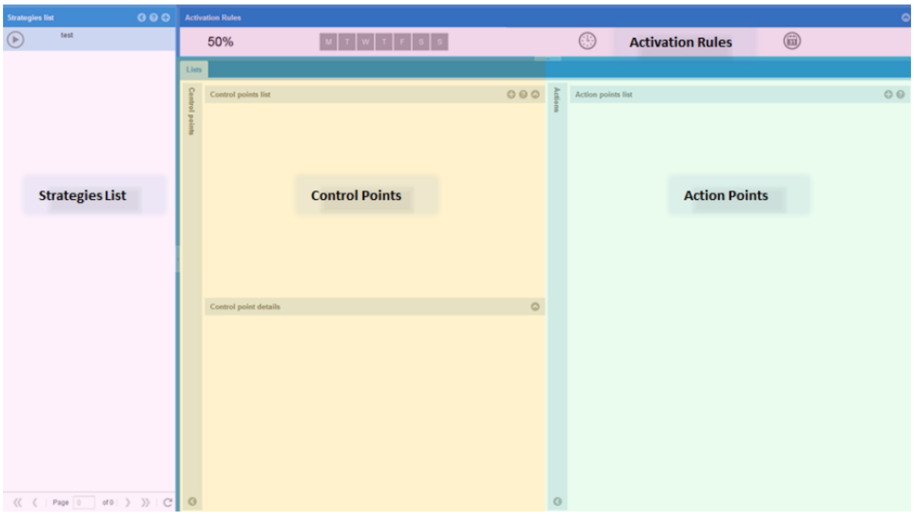


Figure 11. Windows layout Strategy manager SWARCO

The strategies list panel shows the list of strategies that are already ready to be used, the control points panel contains the points that helps the software to react when there is a change in the traffic situation and traffic forecasts. Finally, the Action points shows the list of the objects that are mean to be controlled, for every action point there is an action to be performed when the strategy is activated.

3. Case of Study Trieste

3.1. City of Trieste

The city of Trieste is the capital of the Friuli-Venezia Giulia region, having more than 200.000 inhabitants being the sixteenth city in order of population in Italy. It has a population density of 2.417 km2 and a total surface of 84,49 km2. It is located over the coast of the golf with its exact name, in the foot of the Karst plateau, between Farnet and Rosandra streams.

History has marked this city; after 1918, when Italy tried to assimilate the new eastern territories, Italy and its nationalists promoted eastern territories known as Venezia Giulia and Venezia Tridentina as an integral to Venetian lands. The Italianisation in the upper Adriatic took around five centuries to facilitate Austrian trade in the Balkans and the Mediterranean. Turning Trieste into both an international port and a border town (Hametz, 2005).

These events have turned Trieste into a reference point of regular and direct ocean connections with the Far East, serving as a stopping point for the leading world shipping companies of the Mediterranean belt. Over 200 trains a week connect Trieste with the production and industrial areas of North-East Italy and Central Europe, with various destinations, such as Germany, Austria, Luxembourg, Slovakia, Hungary, Belgium, and the Czech Republic. Highly specialized intermodal services have been developed with direct trains organized by Alpe Adria S.p.a., a neutral multi-client operator, which offers "all-in" packages with guaranteed yield and frequency to reach the reference markets of Central-Eastern Europe. (Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone, 2014).

Figure 12. Trieste connection (Port of Trieste, Trieste port Authority)

Its political division is organized with the division into seven circumscriptions:

1. I Circoscrizione – Altipiano Ovest: It has a total surface of 10,19 km^2 comprising four historic borgo, Santa Croce, Prosecco, Contovello and Borgo San Nazario. Most of the population has an Slovenian origin.

2. II Circoscrizione - Altipiano Est: It is the most extended circumscription, and it confines with Slovenia.
3. III Circoscrizione – Roiano-Gretta-Barcola-Cologna-Scorcola: It is divided into two sub-divisions; the north-ovest zone and the sud-est one.
4. IV Circoscrizione – Città Nuova – Barriera Nuova – San Vito – Città vecchia: It has a total surface of 5.17 km^2. It is the downtown of the city.
5. V circoscrizione -Barriera Vecchia- San Giacomo: It comprises the historic borgos of Barriera Vecchia, San Giacomo and Santa Maria Maddalena Superiore. It is the most habitated one, with the maximum density and the maximum concentration of foreign people.
6. VI Circoscrizione – San Giovanni – Chiadino -Rozzol: It is located in the north-east part of the downtown.
7. VII Circoscrizione – Servola – Chiarbola – Valmaura – Borgo San Sergio: It is in the west side of the downtown.

Codice	Descrizione	Superficie (Km²)
Circ. 1	ALTIPIANO OVEST	10,19
Circ. 2	ALTIPIANO EST	35,02
Circ. 3	ROIANO-GRETTA-BARCOLA-COLOGNA-SCORCOLA	10,22
Circ. 4	CITTA' NUOVA-BARRIERA NUOVA-S. VITO-CITTA' VECCHIA	5,20
Circ. 5	BARRIERA VECCHIA-S. GIACOMO	3,14
Circ. 6	S. GIOVANNI-CHIADINO-ROZZOL	8,48
Circ. 7	SERVOLA-CHIARBOLA-VALMAURA-BORGO S. SERGIO	12,24
Circ. 8	CIRCOSCRIZIONE NON DEFINITA	0,00

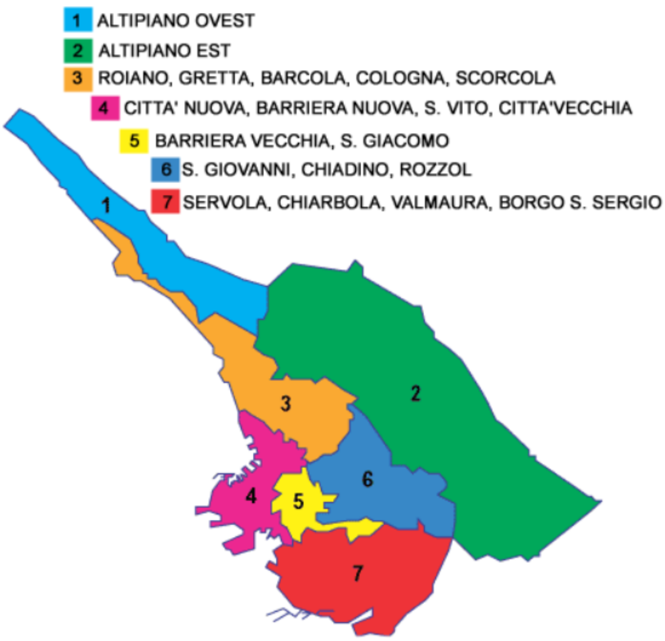


Figure 13. Seven circumscriptions of Trieste (Comune di Trieste)

3.2. Port of Trieste

Located in the heart of Europe, at the meeting point between the maritime routes and the European, Adriatic-Baltic, and Mediterranean corridors, the Port of Trieste is an international hub for land-sea interchange flows affecting the dynamic market of Central and Eastern Europe (Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone, 2014).

The trade's intensification and maritime traffic between the Far East and Europe and the enlargement of the European Union to the East have relaunched the centrality of the Upper Adriatic. They have opened renewed opportunities for growth and development in Trieste. In this context, Trieste plays a decisive role on two distinct logistic chains: long-range intercontinental maritime connections and intra-Mediterranean short-medium-range relations. The meeting between the TEN-T strategic axes of the "Motorways of the Sea of the Eastern Mediterranean" and the European Adriatic-Baltic and Mediterranean corridors determines the growth of intermodality and the development of innovative solutions in the field of logistics and transport (Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone, 2014).

The Port of Trieste has an internal railway network (70 km of tracks) integrated with the national and international network, which allows all the docks to be served by tracks. However, the road network's efficiency is guaranteed by a direct link and an elevated road (inside the port) that enters the external road system, connected with the motorway network (Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone, 2014).

Depths up to 18 meters deep, excellent nautical accessibility, excellent rail and road connections, proximity to the outlet markets make the Port of Trieste an efficient and competitive port. Trieste, a natural crossroads between East and West, is proposed as a preferential gateway from Europe to the Far East markets. In this sense, the Port of Trieste can save four days of navigation on the routes between Europe and East Asia, compared to the ports of call in Northern Europe. For a line of 6,000 TEU container ships, this translates into economic savings on freight and fuel costs of over $ 25 million per year (Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone, 2014).

Greater automation and mechanization of work on the quays have been implemented to allow port facilities to receive modern types of traffic. Growing synchrony of maritime-port activities with road and rail transport (intermodality and logistics) is sought, thanks to the introduction of modern technological innovations applied to the management and coordination of transport products (tracking & tracing), employing telematic tools that are easy to access and use. The terminal is equipped with a broadband connectivity infrastructure (optical fiber), integrated with a high-speed WI-FI connection network (Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone, 2014).

With the entry into the new century, year after year, there has been a strong development of intermodal railway services and passenger traffic and tourism linked to the sea (pleasure craft and cruises). This complex profile, made up of history, technical skills, and material resources, represents the strength on which the port of Trieste can now count to fully recover its traditional role of centrality in the European and Mediterranean economic space. Being now a key point for the Mediterranean corridor and the Baltic-European corridor (Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone, 2014).

Figure 14. Trieste position for Baltic-Adriatic and mediterraenan corridor (Trieste Port Authorities, 2021)

Technical information about the port:

- Port areas: approximately 2.3 million square meters of which approximately 1.8 million square meters of free zones.
- Storage areas: approximately 925,000 square meters of which approximately 500,000 square meters are covered.
- Quay's length: 12 Km.
- Operational berths: 58 (for conventional, multi-purpose ships, container ships, Ro-Ro / ferries, oil tankers, chemical tankers, passengers, etc.).
- Maximum backdrops: 18 m.
- Railway track length: 70 km.

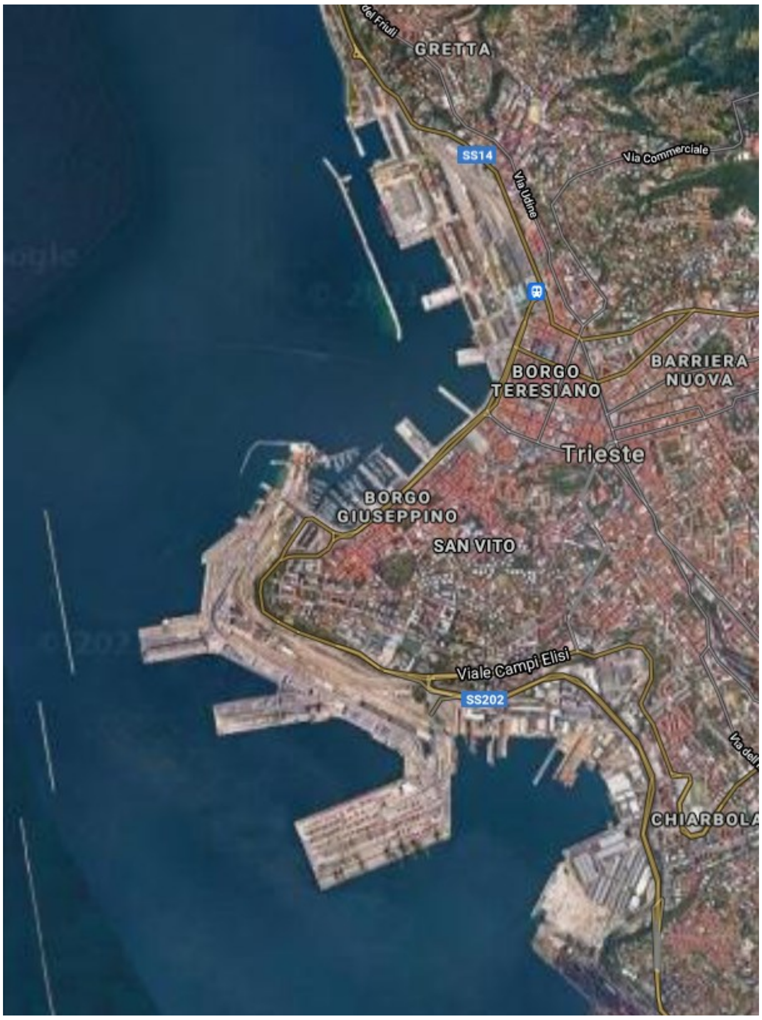


Figure 15. Satellital imagine of the Trieste's port (google maps)

The area of interest for this thesis project, considering the current demand and the growing one, is related to Dock VII and NPL (Nuova Piattaforma Logistica). The idea is to study the impact of having the present maritime traffic into the inland traffic system; so, it has been chosen between the more prominent and most crucial Dock with the developing sector of NPL.

3.2.1. Dock V VI VII – PORTO FRANCO NUOVO

The port authorities name the Dock V, VI, and VII as Porto Franco Nuovo, and all together are the container terminal. It is located in the northwest part of Muggia bay, mainly an industrial and commercial port (Nautica Editrice S.r.l, 2015). The Autorità Portuale di Trieste in their brochure made about the Port of Trieste, explain the terminal operators and the function of each part of the port. In this order of ideas, the Dock V is composed of the fruit terminal and is operated by Terminal Frutta Trieste S.p.a

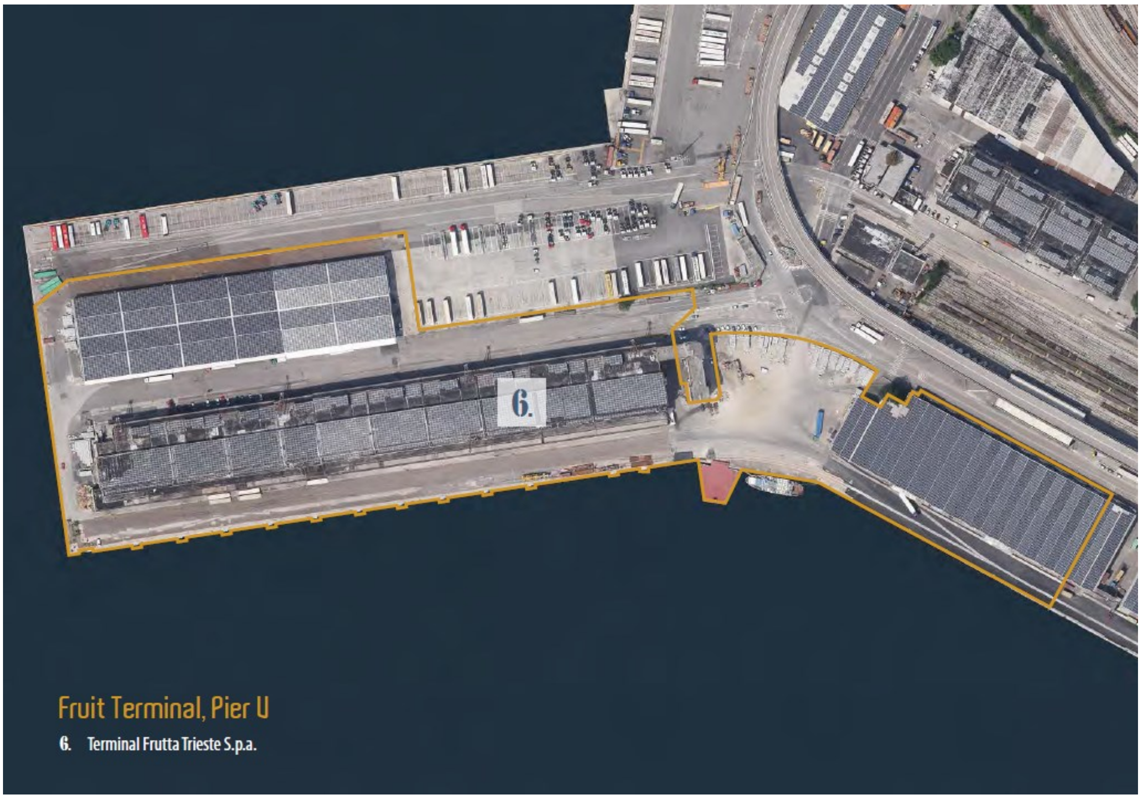


Figure 16. Fruit terminal (Autorità Portuale di Trieste)

The segment between Dock V and Dock VI is composed by the General Cargo Terminal, warehouses 58 and 66, being managed by Tergestea S.r.l and Romani & C. S.p.a.

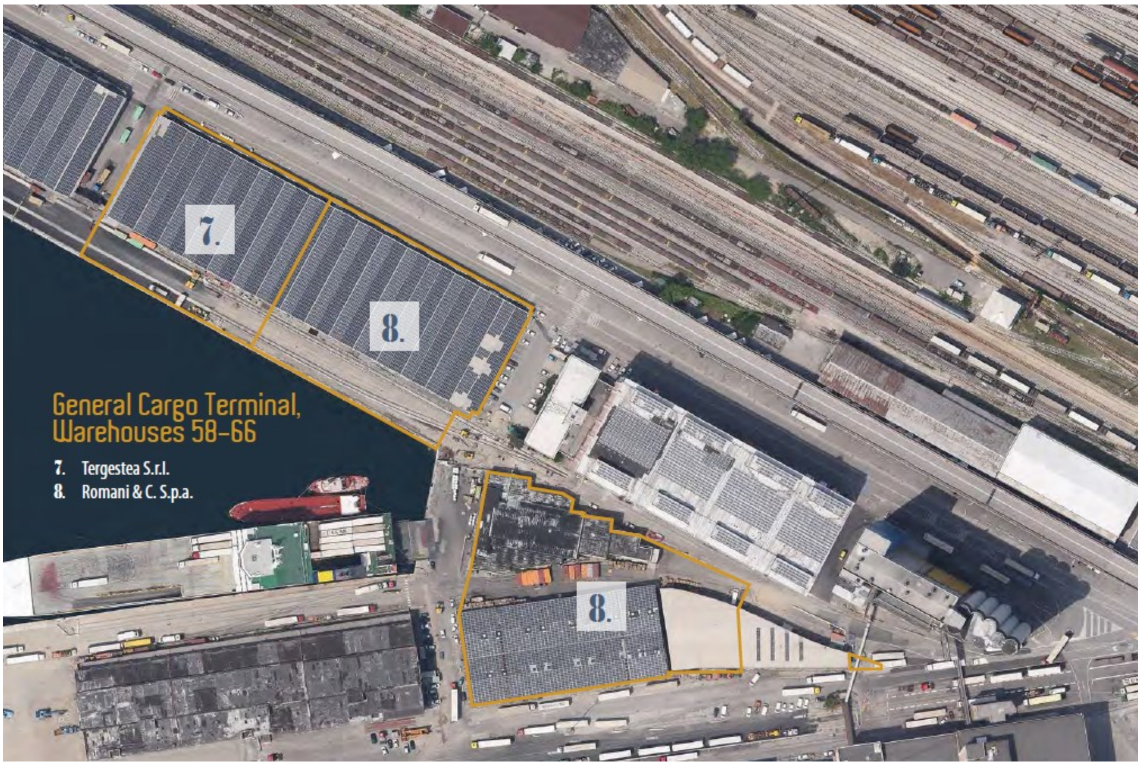


Figure 17. General Cargo Terminal, Warehouses 58-66 (Autorità Portuale di Trieste)

The Dock VI is articulated into a Multipurpose Terminal being driven by Europa Multipurpose Terminals (EMT) S.r.l. and the Grain Terminal managed by Grandi Mollini Italiani S.p.a.

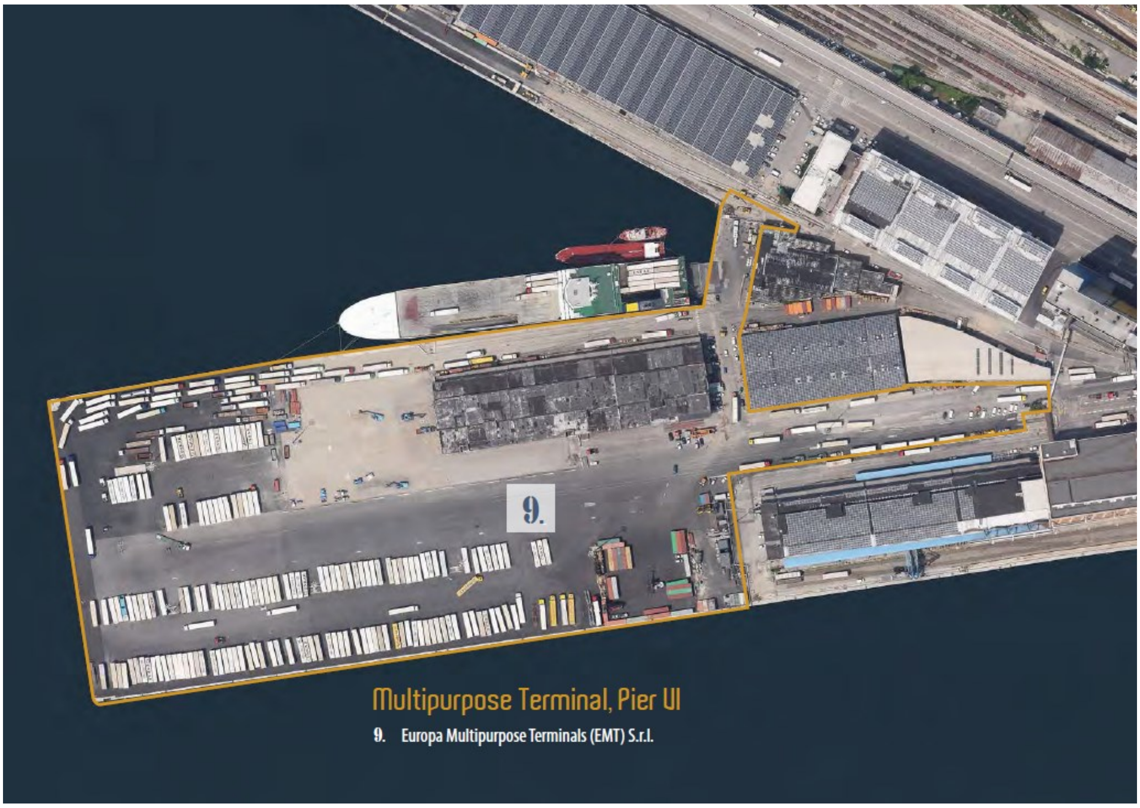


Figure 18. Multipurpose Terminal (Autorità Portuale di Trieste)

Figure 19. Grain Terminal (Autorità Portuale di Trieste)

On the other hand, Dock VII that is the biggest one is composed of the Terminal Polo Caffè, the Ro-Ro Terminal, and the container terminal; having a couple of companies that manage this part of the port: Pacorini Silocaf S.r.l., Trieste Intermodal Maritime Terminal S.r.l. and Trieste Marine Terminal S.p.a.

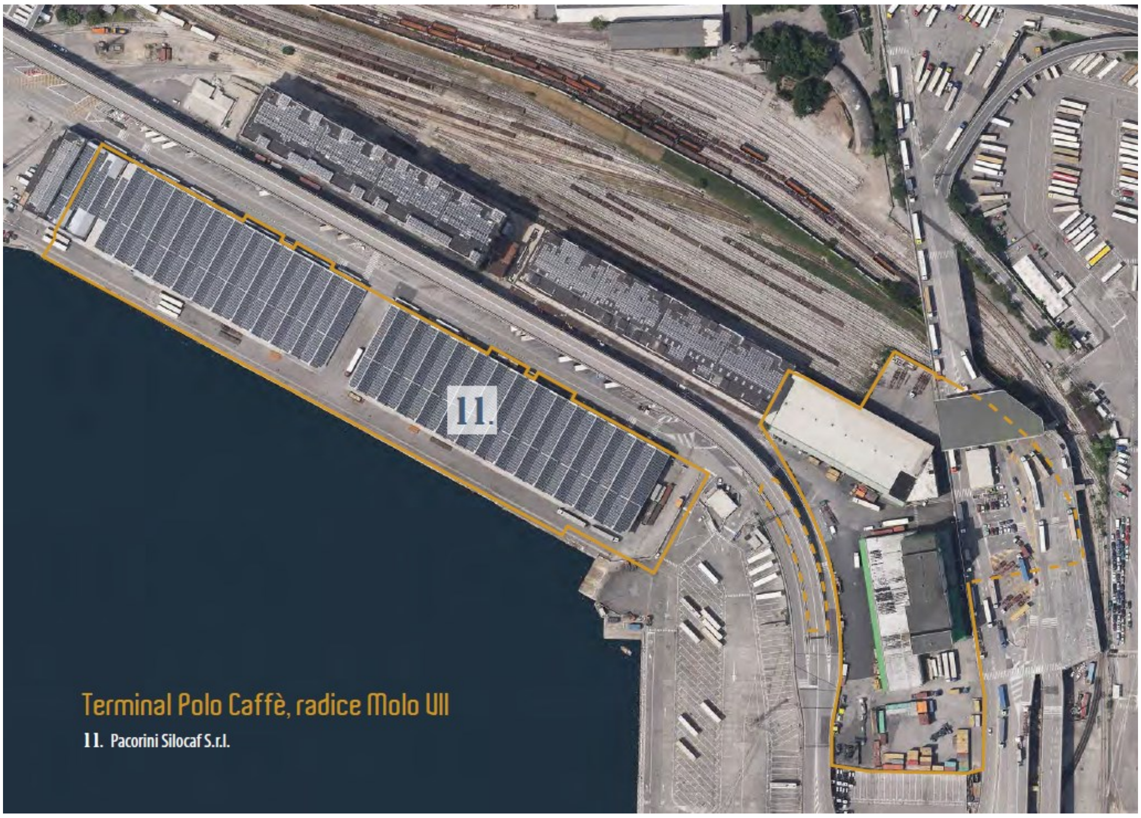


Figure 20. Terminal Polo Caffè (Autorià Portuale Trieste)

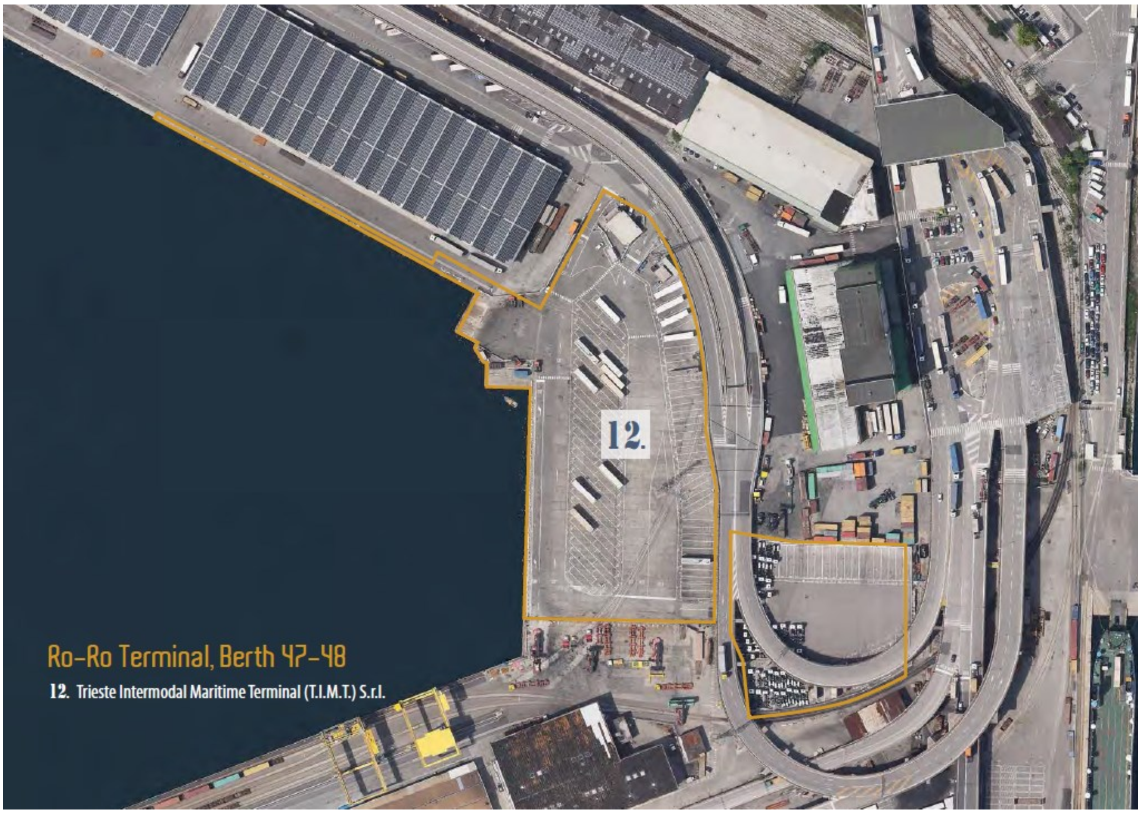


Figure 21. Ro-Ro Terminal (Autorità Portuale Trieste)

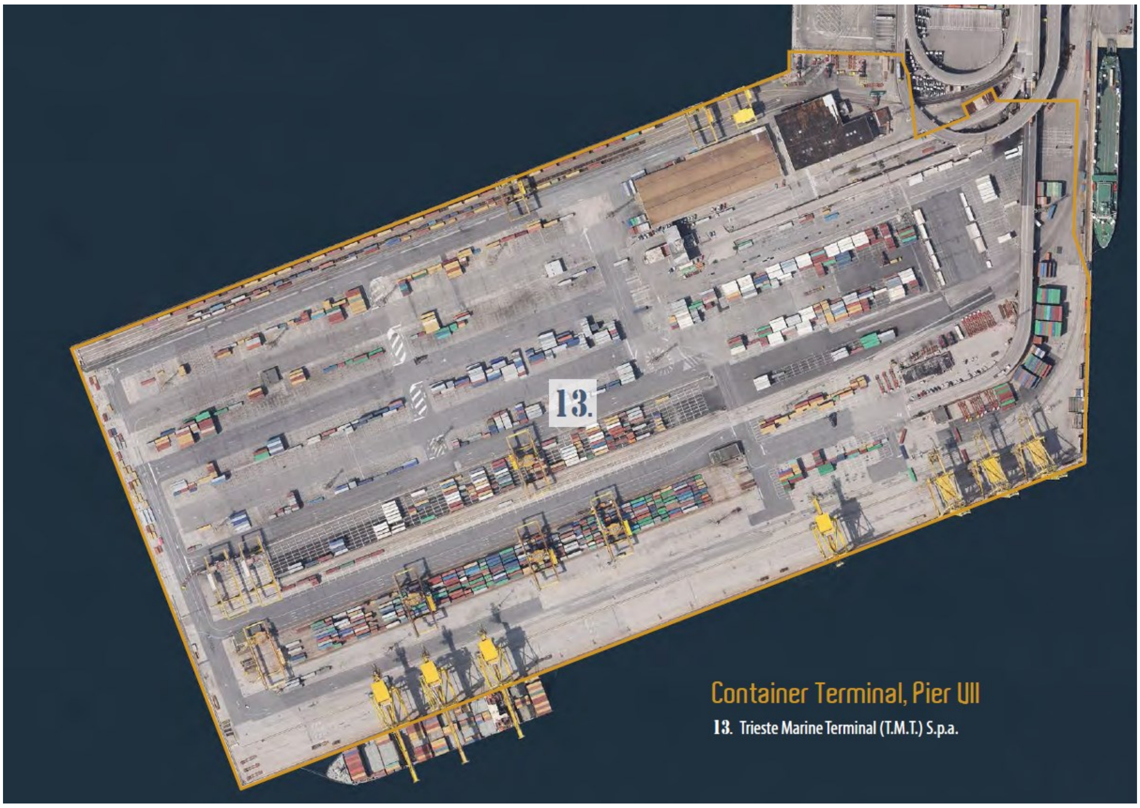


Figure 22. Container Terminal (Autorità Portuale di Trieste)

This part of the port is internally connected by a system of internal streets and a railway system, having as a principal axis the Molo Fratelli Bandiera and the principal access in the intersection of Passeggio Sant'Andrea, la Nuova Sopraelevata, and Viale Campi Elisi, representing this entrance a crucial point regarding traffic inland congestion.

Figure 23. Porto Franco Nuovo Entrance (Google Maps)

The Autorità Portuale di Trieste in their document Piano Regolatore Portuale di Trieste (2011), directed by Eric Marcone, express that Porto Franco Nuovo represents an enormous contribution of the embarkation and disembarkation goods of the total Trieste statistics. In 2007, Porto Franco Nuovo represented 58% of the total landed merchandise while it had the 89% of the total loading goods (Figure 23 and Figure 24); this information represented a start point in the definition of the study zone, taking as a reference the principal entrance of the most transit part of the port, that is why this point had been selected as the initial segment of the model.

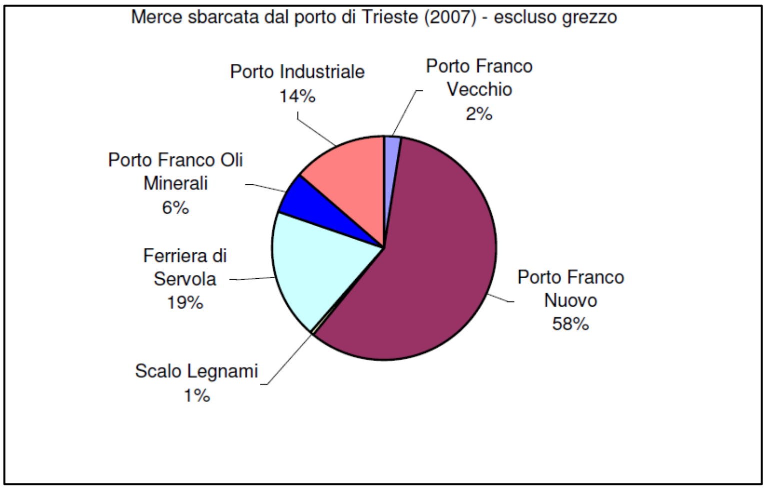


Figure 24. Total landed merchandise 2007 (Autorità Portual di Trieste)

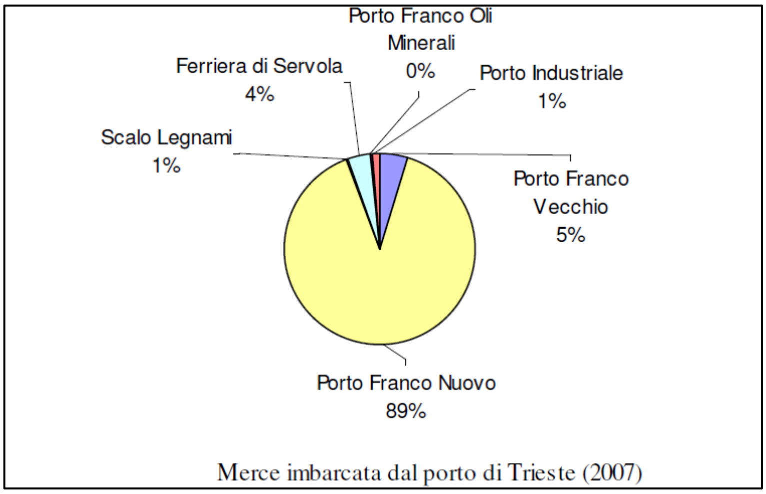


Figure 25. Total shipped merchandise 2007 (Autorità Portuale di Trieste)

3.2.2. NPL (Nuova Piattaforma Logistica)

The Nuova Piattaforma Logistica is an essential part of the Italian seaport, and it is located in the Free Trade zone of the city of Trieste and takes into account warehouses, sheds, and yards a total surface of around 270.000 m2 (HHLA.de). The Port Authorities exposes in their brochure about the port the intention of expanding this area. The project involves the creation of new docks between the Timber Terminal and the Servola Ironworks.

Figure 26. Multipurpose Terminal (Autorità Portuale di Trieste)

Figure 27. Ironeorks, metals terminal (Autorità Portuale di Trieste)

Nowadays, the terminal is composed of two main berths of 360 meters and 414 meters. The draft may be variable, from a minimum of 9 meters to a maximum of 13 meters. As said before, the NLP is a multipurpose terminal, able to manage containers, ro-ro, general cargo, and project cargo. The objective is to turn this zone into the future interchange platform between sea and rail on the Baltic and Mediterranean railway (Autorità Portuale of Trieste). It was considered a vital zone into the study area definition given that the maritime traffic is being increased towards this zone. The idea was to consider how the inland traffic would behave in the future with the saturation of this zone.

4. Model and analyzed simulation

It has been chosen a segment of the SS202 that composes the Nuova Sopraelevata to analyze the inland movements that regard the Porto Franco Nuovo and the Nuova Piattaforma Logistica (NPL). This motorway is part of the extensive infrastructure called Grande Viabilità Triestina (GVT), known as the road connection with highway characteristics between the Italian city of Trieste, the rest of the country, and the neighboring country of Slovenia.

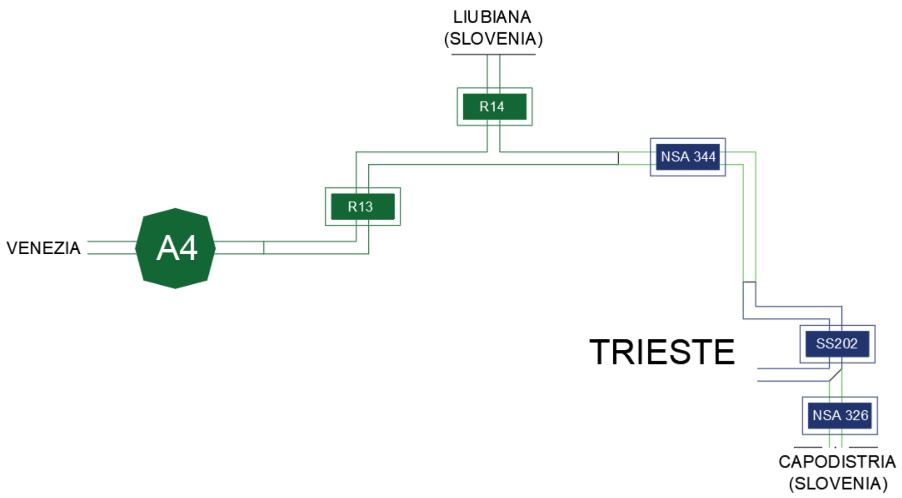


Figure 28. GVT Simplified highway diagram

The chosen segment is the part of the SS202 that links the entry of the Porto Franco Nuovo with the NPL zone—having as a central node the intersection between the SS202, Passaggio

Sant'Andrea, and Viale Campi Elisi, composed of four entrances and four exits. The SS202 extends until it arrives at NPL Zone. The full extension of the model is 3 km (approx.)

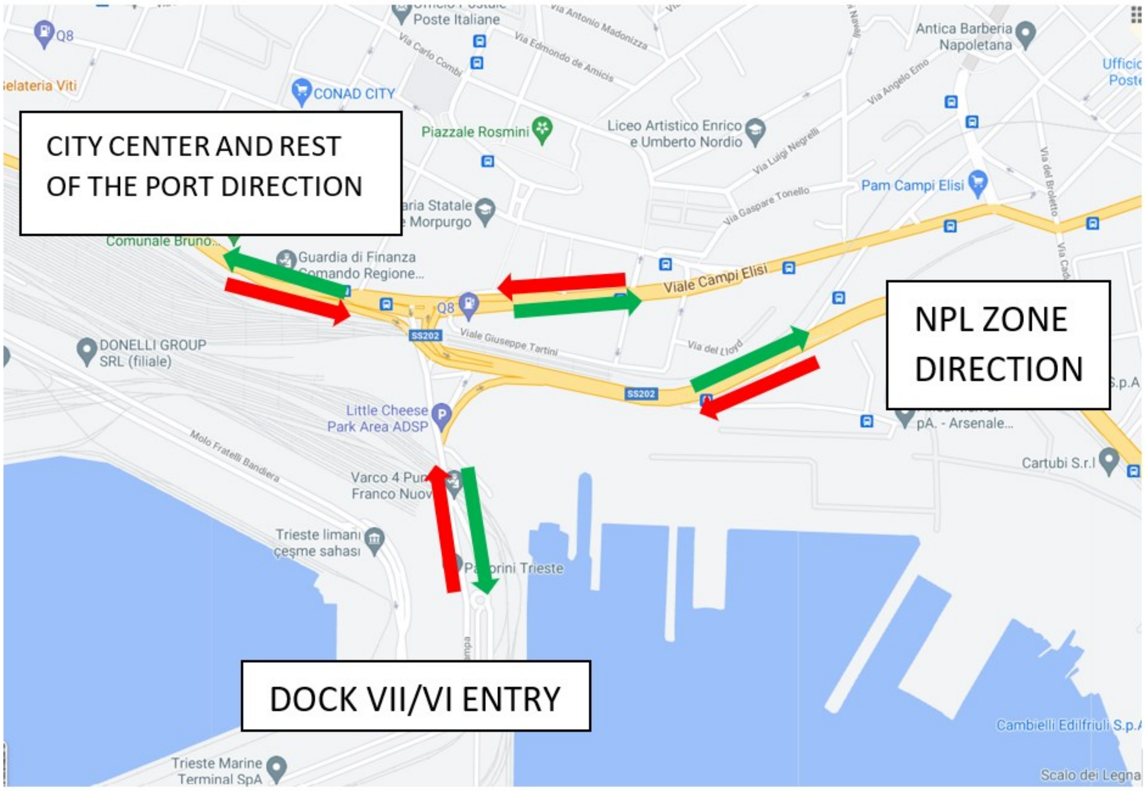


Figure 29. SS202 Intersection schematization. (Google Maps)

In the following figure, it is shown the total chosen segment drawn in Aimsun.

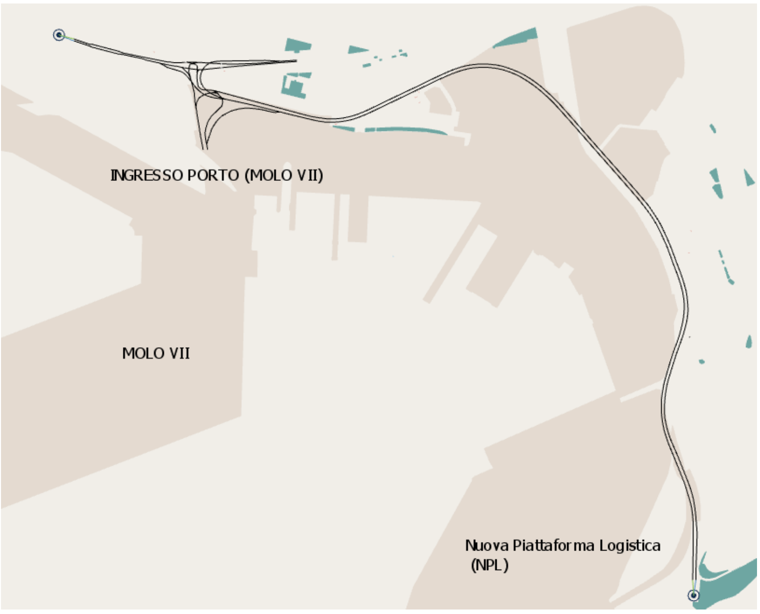


Figure 30. Model schema (AIMSUN)

4.1. Adaptation of Trieste's traffic study – Development of base O/D matrix

To carry out the traffic demand simulation, as expressed before it was decided to consider only one part of the matrix, doing a re-zoning adapting the available survey to this case study. As explained first, the municipality of Trieste was contacted to obtain accurate traffic data having access to a traffic demand study that was made in the spring of 2019 for the morning critical hours (7:30 am -8:30 am). The data supplied by the municipality contained two complete Origin/Destination matrices, one for cars, the other one for trucks, and its respective zone distribution.

Figure 31. Trieste zonification, Municipality traffic study

Thus, to delimitate the study zone, the respective zones that affect the traffic had been regrouped into four new zones for each centroid. The first zone (Figure 32) is the one regarding the downtown, and it is indicated with blue. The second zone (Figure 33) is the one regarding the entrance of the port zone; in this zone, all the movements have an origin or destination to the Porto Franco Nuovo. This one is indicated with yellow. The third zone (Figure 34) is the one regarding the neighborhood of Chiarbola that is adjacent to the chosen segment, and it is indicated with pink. The four and last zone (Figure 35) is indicated with green, and it is the one that involved the NPL zone, Valmaura, and Servola neighborhood.

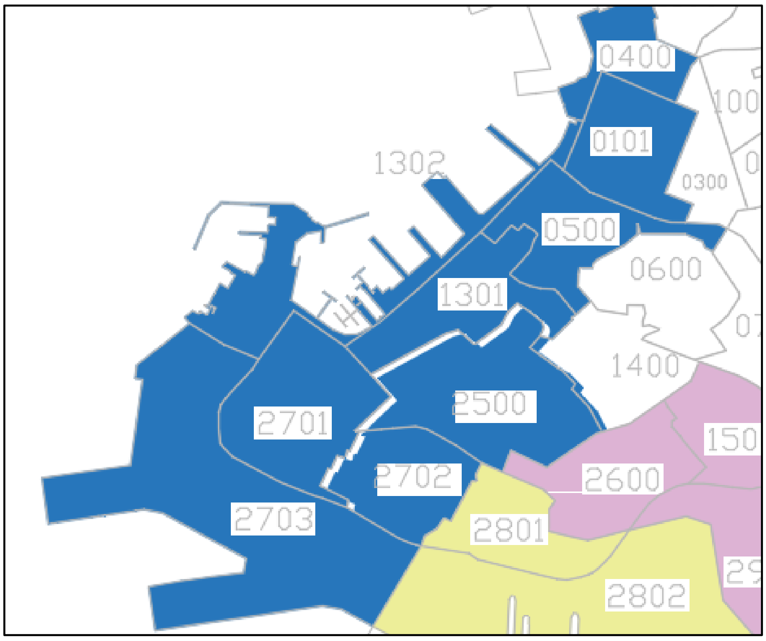


Figure 32. Zone 1 (Downtown and Port upstream's zones, blue one)

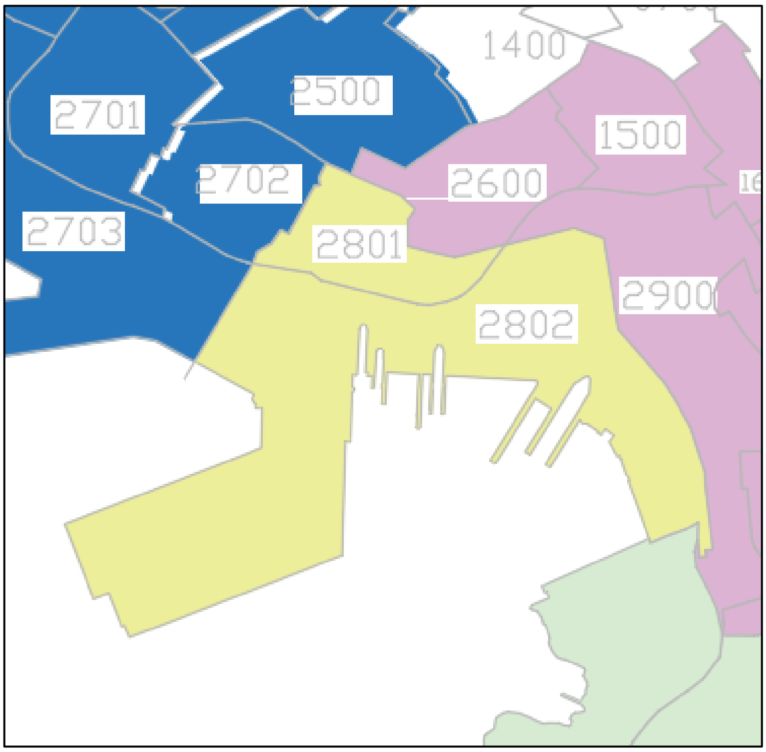


Figure 33. Zone 2 (Entrance port zones, yellow one)

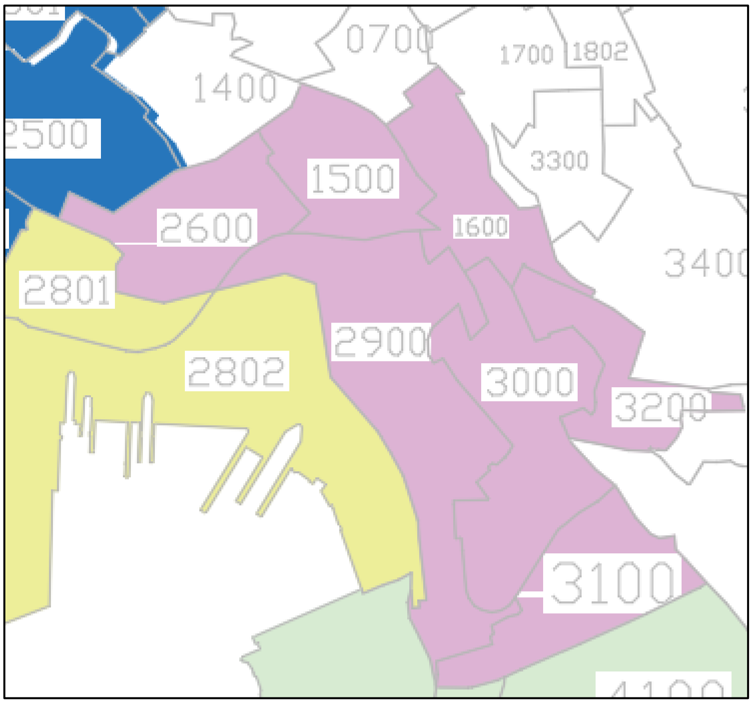


Figure 34. Zone 3 (Chiarbola neighborhood, pink one)

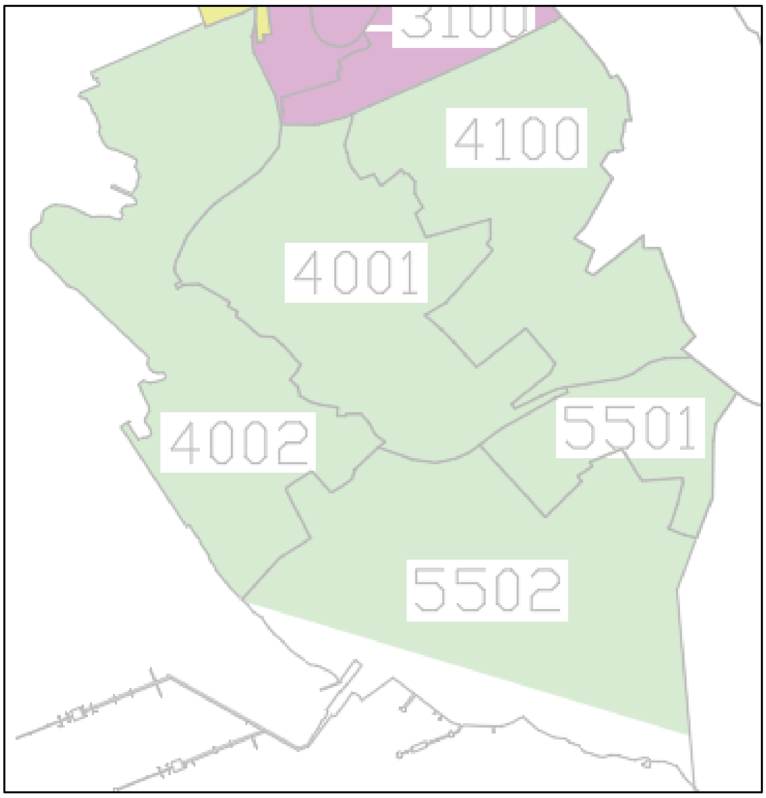


Figure 35. Zone 4 (NPL, Valmaura and Servola neighborhood, green one).

It was determined the original zones that would now belong to the new re-aggrupation configuration. Zone 1 is composed of 9 of the original zones, Zone 2 by 2, Zone 3 by 7, and zone 4 by 5, as shown in the following table:

Table 2. Re-distribution of traffic study zones in the new configuration

ZONE 1	ZONE 2	ZONE 3	ZONE 4
MINI ZONA	MINI ZONA	MINI ZONA	MINI ZONA
101	2801	1500	4001
400	2802	1600	4002
500		2600	4100
1301		2900	5501
1302		3000	5502
2500		3100	
2701		3200	
2702			
2703			

The next step was to identify how many trips were done from one zone to another based on the original O/D matrix. Therefore, we correlate Zone 1 to Zone 2, and it was counted how many trips were done from zone 101 to 2801 and 2802; then how many trips were done from zone 400 to zone 2801 and zone 2802 and so on until determining all the trips that were done between zone 1 and zone 2. Then the same process was carried out for the trips between zone 1 to zone 3 and zone 4, and finally, the same process was performed for the other zones for both light-vehicles and heavy-vehicles. Hereafter are presented the tables showing the trips accounting for both types of matrixes:

Table 3. Trips accounting for Zone 1 for light-vehicles

Z1	Z2	TRIPS	Z1	Z3	TRIPS	Z1	Z4	TRIPS
101	2801	0,034	101	1500	0,161	101	4001	0,01
	2802	0,004		1600	0,32		4002	0,008
400	2801	0,019		2600	0,009		4100	0,013
	2802	0,092		2900	0,055		5501	0,001
500	2801	0		3000	0,601		5502	0
	2802	0		3100	0,017	400	4001	0,152
1301	2801	0		3200	0,007		4002	0,009
	2802	0	400	1500	0,881		4100	0,443
1302	2801	0,282		1600	0,166		5501	0,001
	2802	6,889		2600	0,29		5502	0
2500	2801	116,953		2900	0,8	500	4001	0
	2802	18,464		3000	0,022		4002	0
2701	2801	0		3100	0,228		4100	0

	2802	0
2702	2801	
	2802	
TOTAL		142,737

	3200	0,16
500	1500	3,952
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
1301	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
1302	1500	0,008
	1600	0,001
	2600	0,001
	2900	0,011
	3000	0,003
	3100	0,001
	3200	0,001
2500	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
2701	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
2702	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	102,454
TOTAL		110,149

	5501	0
	5502	0
1301	4001	0
	4002	0
	4100	3,444
	5501	0
	5502	0
1302	4001	0,001
	4002	0,002
	4100	0
	5501	
	5502	0
2500	4001	58,476
	4002	0
	4100	59,294
	5501	0
	5502	0
2701	4001	0
	4002	0
	4100	0
	5501	0
	5502	0
2702	4001	0
	4002	0
	4100	0
	5501	0
	5502	0
TOTAL		121,854

Table 4. Trips accounting for Zone 1 for heavy-vehicles

Z1	Z2	TRIPS
101	2801	0,001
	2802	0
400	2801	0,001
	2802	0,003
500	2801	0,099
	2802	0,023
1301	2801	0,581
	2802	0,038
1302	2801	0,013
	2802	0,011
2500	2801	2,165
	2802	0,111
2701	2801	1,851
	2802	0,098
2702	2801	0,841
	2802	0,032
TOTAL		5,868

Z1	Z3	TRIPS
101	1500	0,018
	1600	0
	2600	0
	2900	0,004
	3000	0
	3100	0
	3200	0
400	1500	0,085
	1600	0
	2600	0
	2900	0,058
	3000	0
	3100	0
	3200	0
500	1500	0,16
	1600	0
	2600	0,044
	2900	0,093
	3000	0
	3100	0
	3200	0
1301	1500	0
	1600	0
	2600	0,17
	2900	0,165
	3000	0
	3100	0
	3200	0
1302	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
2500	1500	1,181
	1600	0
	2600	0,494
	2900	0,519
	3000	0
	3100	0,157
	3200	0
2701	1500	0,862

Z1	Z4	TRIPS
101	4001	0
	4002	0,001
	4100	0
	5501	0
	5502	0
400	4001	0
	4002	0,001
	4100	0
	5501	0
	5502	0
500	4001	0
	4002	0,002
	4100	0
	5501	0
	5502	0
1301	4001	0
	4002	0,033
	4100	0
	5501	0,001
	5502	0
1302	4001	0
	4002	0
	4100	0
	5501	0
	5502	0
2500	4001	0,115
	4002	0,115
	4100	0,077
	5501	0,015
	5502	0
2701	4001	0,046
	4002	0,074
	4100	0,044
	5501	0
	5502	0
2702	4001	0,041
	4002	0,015
	4100	0,088
	5501	0
	5502	0
TOTAL		0,668

	1600	0
	2600	0,317
	2900	0,336
	3000	0,136
	3100	0,06
	3200	0
2702	1500	0,234
	1600	0
	2600	0,177
	2900	0,153
	3000	0,07
	3100	0,001
	3200	0,015
TOTAL		5,509

Table 5. Trips accounting for Zone 2 for light-vehicles

Z2	Z1	TRIPS
2703	101	0
	400	0
	500	0
	1301	0
	1302	0
	2500	0
	2701	0
	2702	0
2802	101	0
	400	0
	500	0
	1301	6,806
	1302	0
	2500	0
	2701	0
	2702	0
TOTAL		6,806

Z2	Z3	TRIPS
2703	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
2802	1500	5,122
	1600	0
	2600	0
	2900	34,979
	3000	0
	3100	0
	3200	0
TOTAL		40,101

Z2	Z4	TRIPS
2703	4001	0
	4002	0
	4100	0
	5501	0
	5502	0
2802	4001	0
	4002	0
	4100	13,178
	5501	0
	5502	0
TOTAL		13,178

Table 6. Trips accounting for Zone 2 for heavy-vehicles

Z2	Z1	TRIPS
2703	101	0
	400	0
	500	0
	1301	0
	1302	0
	2500	0

Z2	Z3	TRIPS
2703	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0

Z2	Z4	TRIPS
2703	4001	0
	4002	0
	4100	0
	5501	0
	5502	0
2802	4001	0

	2701	0
	2702	0
2802	101	0,006
	400	0
	500	0,124
	1301	0,091
	1302	0,057
	2500	0,06
	2701	0,226
	2702	0,003
TOTAL		0,567

	3200	0
2802	1500	0,032
	1600	0
	2600	0,001
	2900	0,034
	3000	0,023
	3100	0
	3200	0,022
TOTAL		0,112

	4002	0,011
	4100	0,03
	5501	0
	5502	0
TOTAL		0,041

Table 7. Trips accounting for Zone 3 for light vehicles

Z3	Z1	TRIPS
1500	101	0
	400	87,638
	500	33,145
	1301	0
	1302	0
	2500	0
	2701	0
	2702	5,25
1600	101	13,675
	400	18,256
	500	20,661
	1301	9,614
	1302	2,206
	2500	2,573
	2701	2,917
	2702	5,465
2600	101	0
	400	0
	500	59,989
	1301	0
	1302	0
	2500	0
	2701	0
	2702	0
2900	101	0
	400	0
	500	0
	1301	0
	1302	0
	2500	0

Z3	Z2	TRIPS
1500	2801	0
	2802	0
1600	2801	3,743
	2802	12,23
2600	2801	0
	2802	18,941
2900	2801	0
	2802	3,73
3000	2801	2,64
	2802	7,5
3100	2801	0
	2802	0
3200	2801	0
	2802	0
TOTAL		48,784

Z3	Z4	TRIPS
1500	4001	0
	4002	0
	4100	0
	5501	0
	5502	0
1600	4001	115,821
	4002	2,937
	4100	2,829
	5501	0,153
	5502	0
2600	4001	0
	4002	0
	4100	71,001
	5501	0
	5502	0
2900	4001	120,482
	4002	0
	4100	3,444
	5501	0
	5502	0
3000	4001	1,445
	4002	1,586
	4100	5,181
	5501	0,004
	5502	0
3100	4001	0
	4002	0
	4100	0
	5501	0
	5502	0

	2701	0
	2702	0
3000	101	3,127
	400	3,359
	500	9,002
	1301	9,553
	1302	1,255
	2500	2,335
	2701	25,987
	2702	14,72
3100	101	0
	400	0
	500	272,81
	1301	2,347
	1302	0
	2500	0
	2701	3,05
	2702	2,889
3200	101	0
	400	0
	500	0
	1301	0
	1302	0
	2500	0
	2701	0
	2702	0
TOTAL		611,823

3200	4001	0
	4002	0
	4100	0
	5501	0
	5502	0
TOTAL		324,883

Table 8. Trips accounting for Zone 3 for heavy-vehicles

Z3	Z1	TRIPS	Z3	Z2	TRIPS	Z3	Z4	TRIPS
1500	101	0,152	1500	2801	0,443	1500	4001	0,194
	400	0		2802	0,025		4002	0,222
	500	0	1600	2801	0,359		4100	0,115
	1301	0		2802	0,044		5501	0
	1302	0	2600	2801	1,458		5502	0
	2500	0,183		2802	0,109	1600	4001	0,134
	2701	0,175	2900	2801	0,858		4002	0,282
	2702	0,156		2802	0,054		4100	0,272
1600	101	0,538	3000	2801	0,221		5501	0,015
	400	0		2802	0,024		5502	0
	500	0	3100	2801	0,414	2600	4001	0
	1301	0		2802	0,204		4002	0
	1302	0,212	3200	2801	0,156		4100	0
	2500	0		2802	0,02		5501	0
	2701	0,203	TOTAL		4,389		5502	0

	2702	0,242
2600	101	0,383
	400	0
	500	0,782
	1301	0,622
	1302	0,086
	2500	0,224
	2701	0,254
	2702	0,535
2900	101	0,618
	400	0
	500	0
	1301	1,428
	1302	0,209
	2500	0,25
	2701	0,303
	2702	0,315
3000	101	0,174
	400	0
	500	0,057
	1301	0,046
	1302	0,007
	2500	0,194
	2701	0,126
	2702	0,21
3100	101	0,366
	400	0
	500	0,094
	1301	0,8
	1302	0,627
	2500	0,21
	2701	1,094
	2702	1,397
3200	101	0,324
	400	0
	500	0,099
	1301	0,056
	1302	0,013
	2500	0,01
	2701	0,143
	2702	0,164
TOTAL		14,081

2900	4001	0,237
	4002	0,237
	4100	0,306
	5501	0,028
	5502	0
3000	4001	0,138
	4002	0,153
	4100	0,167
	5501	0
	5502	0
3100	4001	0,221
	4002	0,316
	4100	0,398
	5501	0
	5502	0
3200	4001	0,085
	4002	0,206
	4100	0,154
	5501	0
	5502	0
TOTAL		3,88

Table 9. Trips accounting for Zone 3 for light-vehicles

Z4	Z1	TRIPS
4001	101	1,153
	400	7,724
	500	10,837
	1301	17,498
	1302	3,575
	2500	3,306
	2701	4,617
	2702	6,549
4002	101	0
	400	0
	500	0
	1301	0
	1302	0
	2500	0
	2701	0
	2702	0
4100	101	0
	400	0
	500	0
	1301	24,886
	1302	6,1
	2500	0
	2701	3,05
	2702	8,666
5501	101	1,035
	400	0,701
	500	0,641
	1301	0,392
	1302	0,069
	2500	0,068
	2701	0,272
	2702	0,389
5502	101	0
	400	0
	500	0
	1301	0
	1302	0
	2500	0
	2701	0
	2702	0
TOTAL		101,528

Z4	Z2	TRIPS
4001	2801	4,936
	2802	3,063
4002	2801	0
	2802	0
4100	2801	4,162
	2802	11,669
5501	2801	0,56
	2802	0,251
5502	2801	0
	2802	0
TOTAL		24,641

Z4	Z3	TRIPS
4001	1500	20,387
	1600	2,351
	2600	14,565
	2900	10,001
	3000	8,119
	3100	15,913
	3200	1,182
4002	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0,425
	3200	0
4100	1500	0
	1600	228,865
	2600	2,889
	2900	10,001
	3000	0
	3100	3,44
	3200	0
5501	1500	13,296
	1600	0
	2600	0,066
	2900	0
	3000	0
	3100	0
	3200	0
5502	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
TOTAL		331,5

Table 10. Trips accounting for Zone 3 for light-vehicles

Z4	Z1	TRIPS
4001	101	0,279
	400	0
	500	0,086
	1301	1,017
	1302	0,127
	2500	0,271
	2701	1,559
	2702	1,069
4002	101	0
	400	0
	500	0,001
	1301	0,002
	1302	0
	2500	0
	2701	0
	2702	0
5501	101	0,529
	400	0
	500	0,083
	1301	0,544
	1302	0,174
	2500	0,093
	2701	0,685
	2702	0,538
5502	101	0
	400	0
	500	0
	1301	0
	1302	0
	2500	0
	2701	0
	2702	0
TOTALE		7,057

Z4	Z2	TRIPS
4001	2801	0,531
	2802	0,222
4002	2801	0
	2802	0
4100	2801	
	2802	
5501	2801	
	2802	
5502	2801	
	2802	
TOTALE		0,753

Z4	Z3	TRIPS
4001	1500	0,718
	1600	0,225
	2600	0,013
	2900	3,285
	3000	0,64
	3100	0,347
	3200	0,114
4002	1500	0,002
	1600	0,019
	2600	0
	2900	0,002
	3000	0
	3100	0,041
	3200	0
5501	1500	0,341
	1600	0,206
	2600	0,009
	2900	0,617
	3000	0,191
	3100	0,177
	3200	0,118
5502	1500	0
	1600	0
	2600	0
	2900	0
	3000	0
	3100	0
	3200	0
TOTALE		7,065

The totals of trips between one zone and the other were summarized in the following tables, creating the base matrixes. Each scenario is based on this configuration and some modifications were done depending on the conditions and hypotheses undertaken for each one of them. The total number of trips per hour for light vehicles is 1878 and 50 trips for the heavy vehicles per hour.

Table 11. New matrix O/D for cars

MATRIX O/D (CARS)				
	ZONE 1	ZONE 2	ZONE 3	ZONE 4

ZONE 1		142,737	110,149	121,854
ZONE 2	6,806		40,101	13,178
ZONE 3	611,823	48,784		324,883
ZONE 4	101,528	24,641	331,5	

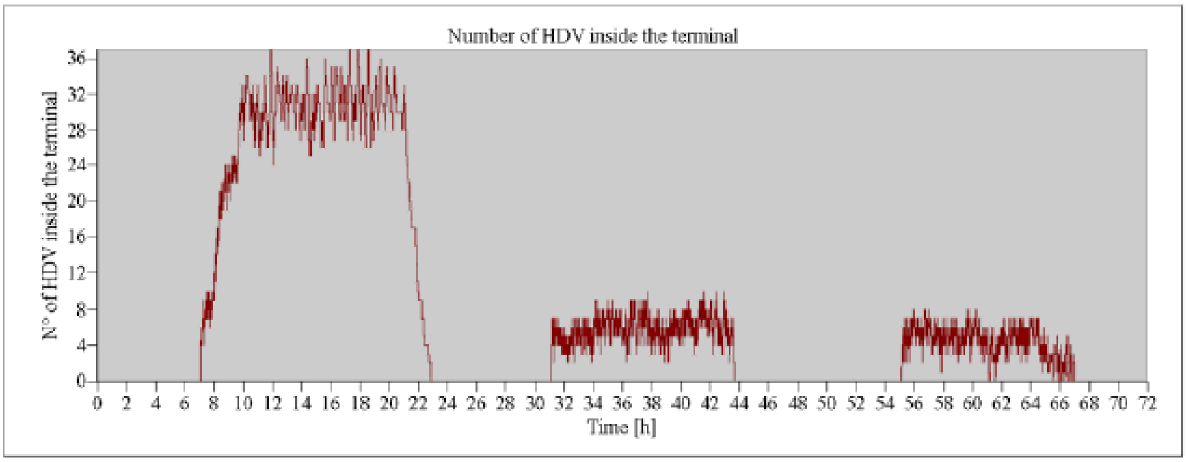
Table 12. New matrix O/D for Trucks

MATRIX O/D (TRUCKS)				
	ZONE 1	ZONE 2	ZONE 3	ZONE 4
ZONE 1		5,868	5,509	0,668
ZONE 2	0,567		0,112	0,041
ZONE 3	14,081	4,389		3,88
ZONE 4	7,057	0,753	7,065	

4.2. Scenario 1 – Initial conditions

For the first scenario, the total time simulation was set up taking as reference the Master Thesis of Marcello Pinna (2021). In his thesis, the aim was to identify the ITS effects in container terminals as far as heavy-duty vehicle queuing is concerned, developing a model in the software Arena that allows the simulation of the port operations. His total time of running was three days, but it was identified, taking as a reference the following graph (Table 13), that the system behaves in more or less 13 hours cycles, so that was the reference total time simulation chosen for this model.

Table 13. Number of HDV inside the terminal (Pinna's thesis output)



The objective of this scenario is to represent the primary traffic conditions. That is why the base matrixes with no modifications were implemented. As only a one-hour matrix was available for the simulation, the O/D matrices for the other 12 hours were hypothesized. For the afternoon's pick hour, 100% percent of the O/D were assigned, while for the previous and post peak's hour of the peak hour a 60% of the matrix was set. A 40% matrix was run for the intermediate hours, composing the Traffic demand for the first scenario.

Table 14. Hypothisized matrix configuration

HOUR	DESCRIPTION
07:00	PRE PEAK HOUR (60% MATRIX)
07:30	PEAK HOUR (100% MATRIX)
08:30	
09:30	POST PEAK HOUR (60% MATRIX)
10:30	INTERMEADIATE HOUR (40% MATRIX)
11:30	INTERMEADIATE HOUR (40% MATRIX)
12:30	INTERMEADIATE HOUR (40% MATRIX)
13:30	INTERMEADIATE HOUR (40% MATRIX)
14:30	INTERMEADIATE HOUR (40% MATRIX)
15:30	INTERMEADIATE HOUR (40% MATRIX)
16:30	INTERMEADIATE HOUR (40% MATRIX)
17:30	PRE PEAK HOUR (60% MATRIX)
18:30	PEAK HOUR (100% MATRIX)
19:30	
20:00	POST PEAK HOUR (60% MATRIX)

The centroid configuration had been set up in the model, then a dynamic scenario was created, and a set of 5 replications were launched to have a greater statistical spectrum. The following figure shows the scenario scheme generated by AIMSUN, showing the situation of the partial simulated flow for that replication; nevertheless, the results will be discussed in the following chapter.

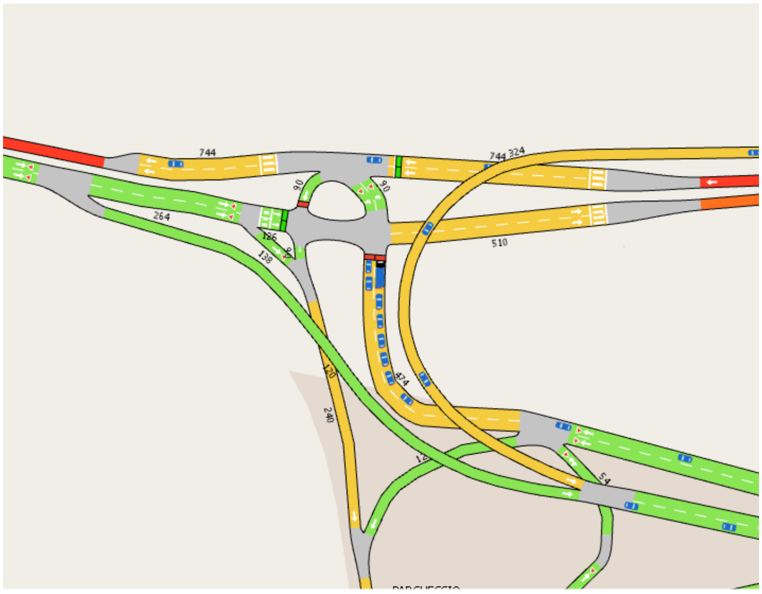


Figure 36. Replication simulation in Aimsun scenario 1

4.4. Scenario 2 – 2011's traffic inland situation generated by the port

For the second scenario, it was considered a basis of the first scenario, so the matrices O/D computed in the previous scenario are also used in this scenario, but some modifications have been made for the heavy vehicle's matrix. The Piano Regolatore Portuale Del Porto Di Trieste (Regulation plan for Trieste's port) (2011) expressed that the port generates flows of the order of 2000 heavy vehicles per day. It would be equal to 4000 light vehicles equivalent, and equal to 500 equivalent light vehicles at rush hour, corresponding to the maximum entry and exit of vehicles, overall, in both directions (entry and exit), and 300-350 light vehicles equivalent in the busiest direction.

In this order of ideas, some hypotheses were made to insert the traffic generated by the port most realistically. The first hypothesis was that the NPL (zone 4) would attract/generates 60% and the Porto Franco Nuovo (zona 2) would attract/generates 40% of the total traffic caused by the port activities, this thinking that NPL is a growing zone that rapidly started to attract a vast quantity of traffic. The question now was which traffic's percentage would be generated and attracted by zone 1 and zone 3 in order to generate the flows in the system? Some hypothesized routes were formulated to answer this question, taking as a reference two critical zones of Trieste (Santa Croce and Cattinara) that match geographically with Zone 1 and Zone 3.

- Trips from Zone 1 to Zone 2: Were equal to the % of trips attracted/generated from Santa Croce to Porto Franco Nuovo.
- Traffic from Zona 1 to Zone 4: Were equal to the % of trips attracted/generated from Santa Croce to NPL.
- Traffic from Zona 3 to Zona 2: Were equal to the % of trips attracted/generated from Cattinara to Porto Franco Nuovo.
- Traffic from Zona 3 to Zona 4: Were equal to the % of trips attracted/generated from Santa Croce to Porto Franco Nuovo.

Figure 37. Santa Croce and Cattinara location respect zone 1 and zone 3

Knowing from Piano Regolatore Portuale Del Porto Di Trieste, these two zones have a Total TGM of 6648 commercial vehicles and know the specific TGM for each zone. Santa Croce has a TGM of commercial vehicles equal to 3.405, and Cattinara has a TGM of commercial vehicles equal to 3.243; it could be calculated that the percentage of flow for Cattinara and Santa Croce, being 48.8% and 51.2 %, respectively. With this hypothesis, the additional O/D for heavy vehicles generated by the port activities was calculated:

Table 15. Additional O/D Matrix for heavy vehicles

	ZONA 1	ZONA 2	ZONA 3	ZONA 4
ZONA 1	0	61,46209	0	92,19314
ZONA 2	61,46209	0	58,53791	0
ZONA 3	0	58,53791	0	87,80686
ZONA 4	92,19314	0	87,80686	0

The previous matrix was added up to the initial heavy vehicle's O/D matrix, and the same hypothesis matrix/time distribution was applied.

Table 16. New O/D matrix for the 2nd scenario

	ZONA 1	ZONA 2	ZONA 3	ZONA 4
ZONA 1	0	67,33009	5,509	92,86114
ZONA 2	62,02909	0	58,64991	0,041
ZONA 3	14,081	62,92691	0	91,68686
ZONA 4	99,25014	0,753	94,87186	0

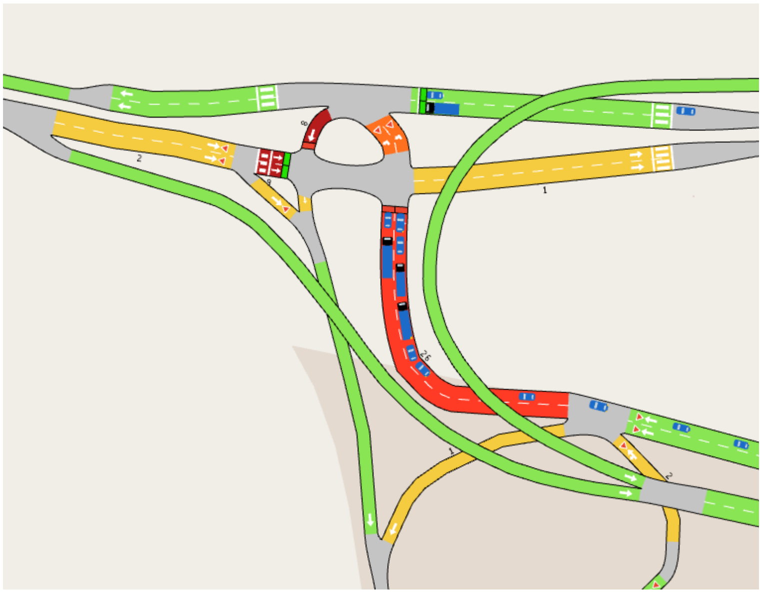


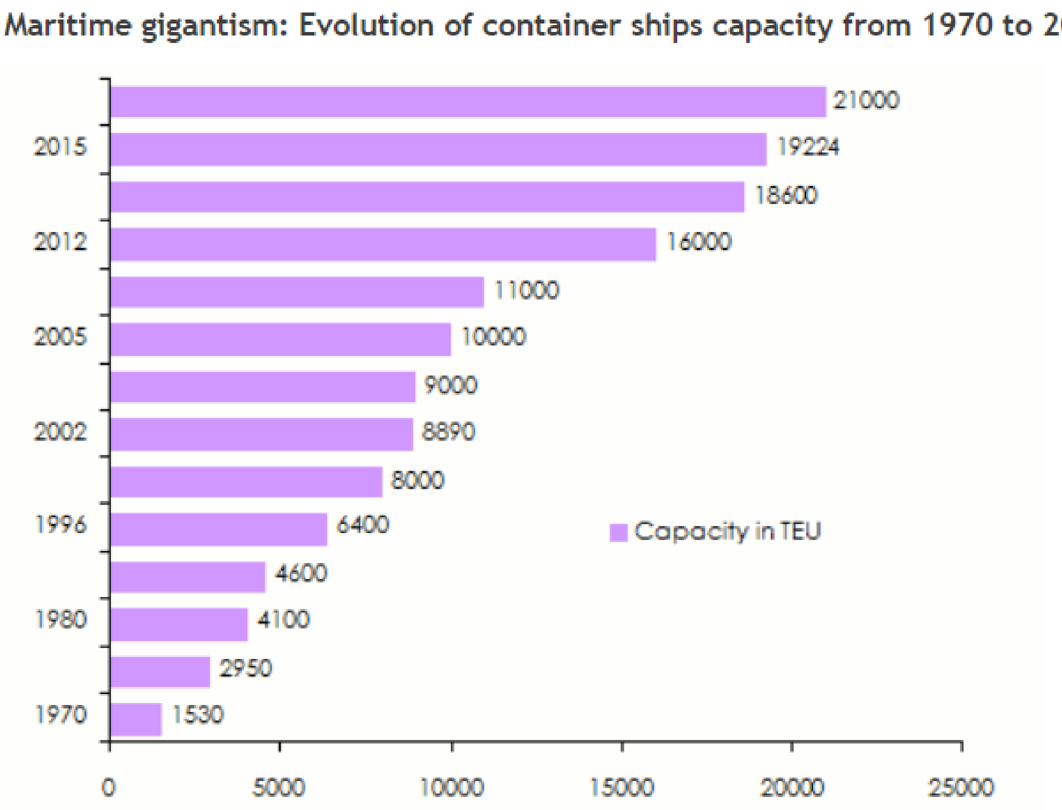
Figure 38. Replication simulation in Aimsun scenario 2

4.5. Scenario 3 – Containerships Gigantism consequences into inland traffic situation

As mentioned, Gigantism's impact on freight transportation has been substantial. It has brought many consequences, some good, like the economic development, some others not much, like congestion and port's saturation. That is why it was considered necessary in this thesis to emphasize the repercussions of this phenomenon in inland traffic.

Pondering that the previous scenario was generated with the PRP of 2011, it was considered that it might not represent the situation that is happening right now in all the ports worldwide, especially in Trieste. As expressed by Prof. Dalla Chiara in his course Sistemi di Trasporto e Logistica Esterna (2019) and reaffirmed by the Atlas Magazine that quotes the Allianz Global & Speciality, from 2011 to the actuality it has been an increment of about 40% in the container ship capacity, that would mirror a 40% of increment in the number of goods that generally transit by container ship mode.

Table 17. Maritime Gigantism (Allianz Global Corporate)



For this reason, it was decided to generate an additional scenario enlarging the heavy vehicle flow generated by the port activities a 40%. This hypothesis produces a new O/D matrix for this new scenario set with the same matrix/time configuration.

Table 18. New O/D matrix for scenario 3 (Maritime gigantism)

	ZONA 1	ZONA 2	ZONA 3	ZONA 4
ZONA 1	0	128,7922	5,509	185,0543
ZONA 2	123,4912	0	117,1878	0,041
ZONA 3	14,081	121,4648	0	179,4937
ZONA 4	191,4433	0,753	182,6787	0

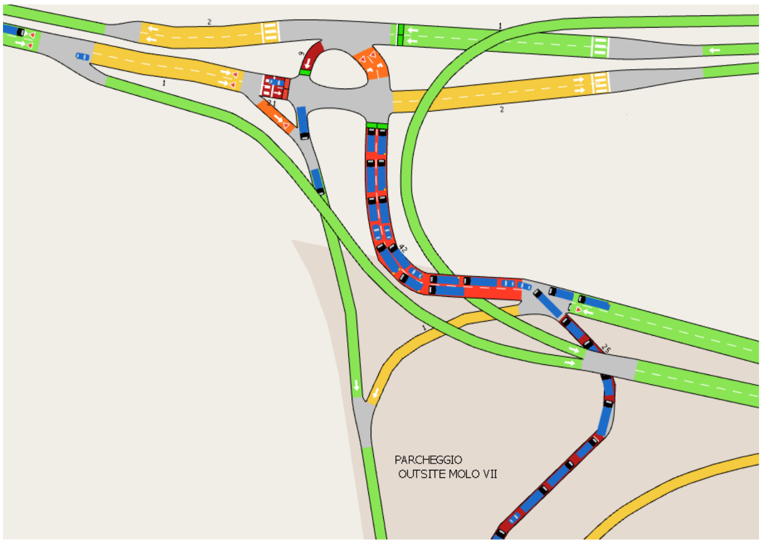


Figure 39. Replication simulation in Aimsun scenario 2

Additionally, the studied segment has an intersection that can be considered as the central node. The semaphoric data of this intersection was not available for the modeling; therefore, 90 s cycles were supposed for the previous scenarios. In this scenario, where we are trying to simulate the actual conditions of the systems, it was suggested another three sub-scenarios where there was a combined different configuration of semaphoric cycles to cover more possible situations and have a more comprehensive view of the problem.

4.5.1. Scenario 3 A – Semaphoric cycle 1

For the scenario 3 A it is considered a 90 second cycle as the previous two scenarios (scenario 1 and 2). It was set a yellow time of 3 sec. Figure *40* represents the first signal group that represents this part of the intersection, Figure *41* represents the second signal group and finally, Figure *42* represents the last signal group.

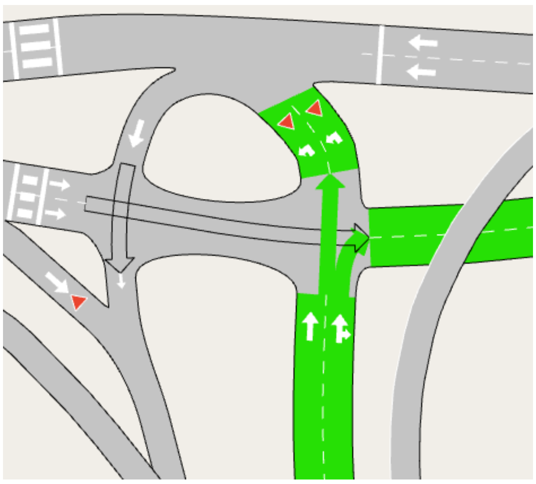


Figure 40. Signal group 1

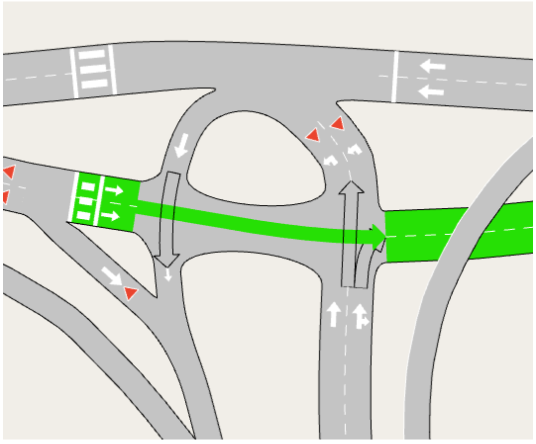


Figure 41. Signal group 2

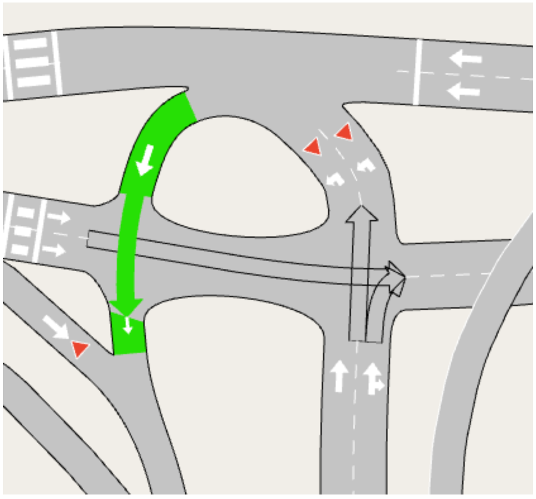


Figure 42. Signal group 3

In the following figure is shown the configuration for the 90 second's cycle:

Figure 43. 90 s cycle configuration

4.5.2. Scenario 3 B – Semaphoric cycle 2

For the scenario 3 B, instead of a 90 second cycle, it is considered a 60 second cycle. The signal groups and yellow time remain the same but there was a reduction of the green time, the idea was to understand what happen to the system with shorter green time cycles. In the next figure is presented the configuration for the 60 second cycle.

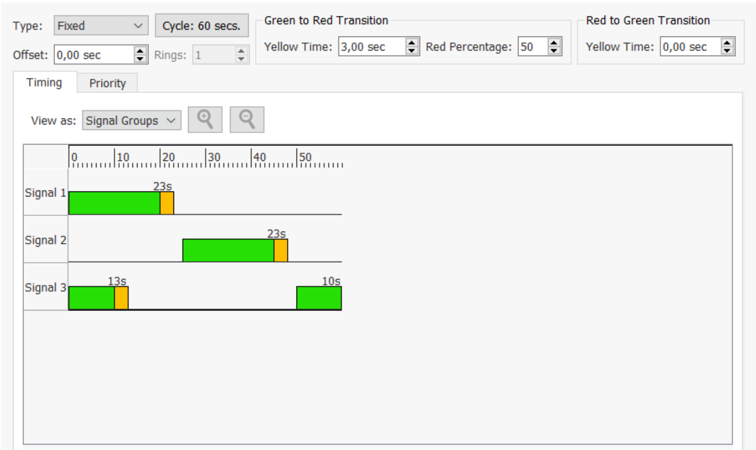


Figure 44. 60 s cycle configuration

4.5.3. Scenario 3 C – Semaphoric cycle 3

For the scenario 3 C, it is considered a 120 second cycle. The signal groups and yellow time remain the same but there was an increase of the green time, the idea was to understand what happen to the system with larger green time cycles. In the next figure is presented the configuration for the 120 second cycle.

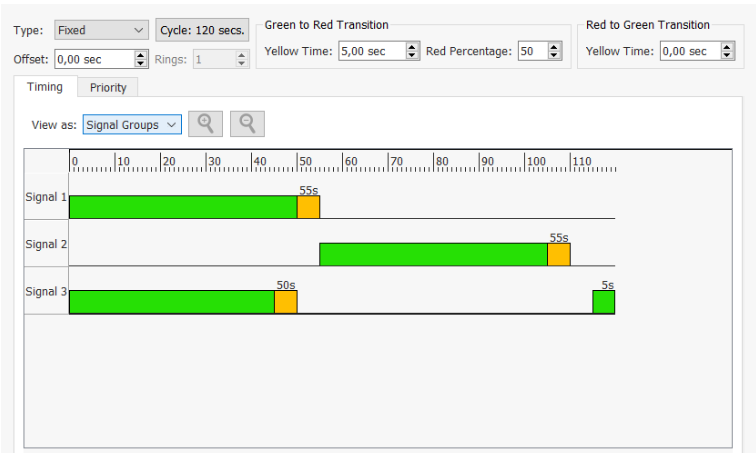


Figure 45. 120 s cycle configuration

4.6. Scenario 4 – Proposed ITS solution for Naval Gigantism situation

As Yulai Wan et al. (2013) expressed, even though urban road capacity expansion is commonly used to solve inland traffic problems, it is sometimes more advisable to implement ITS as an alternative. The high cost of urban road capacity expansion and the unwieldy that can be to stop the entire production and functioning of a sector make less convenient the realization of such interventions. Besides, it is not said that urban road capacity improves the throughput of the system. In Yulai Wan et al. (2013), it was demonstrated that this kind of intercession had a negative impact on the overall performance of Baltimore, LALB, Miami, Baltimore, Boston, Charleston, Hampton Roads, Jacksonville, Oakland, Portland, and SeaTac.
During the development of this Master Thesis, two solutions to Trieste Inland Traffic problems were formulated:

- The first solution was implementing a variable message system that would be carried out through a configuration of physical and virtual VMS that will keep updated all the users about traffic conditions in the critical zones—communicating to heavy vehicles driver the necessity of not transiting into the critical zones during the most congested hours, using the buffer areas system that Pinna previously studied (2021) in his master thesis.

  A VMS (variable-message sign) is an electronic traffic sign often used on roadways to give travelers information about special events. Such signs warn of traffic congestions, accidents, roadwork zones, etc. In urban areas, VMS are often used within parking guidance and information systems to communicate the users the free spots, or they are also often used to ask vehicles to take alternative routes, limit travel speed, location of the incidents, etc. Physical VMS are signals that are already placed in the infrastructures, so it is necessary to consider combining this solution with options that allows to act in advance, or with an anticipated communication system to the companies or more specifically with broadcast system in case of considerable queues.

Figure 46. Physical VMS (https://www.aesys.com/products-solutions/traffic/variable-message-sign-vms.html)

Virtual VMSs are exploiting In Vehicle Information. They are simulating real VMS but information is only transmitted directly to the drivers through V2x; they are positioned in strategic positions with the goal to inform drivers of important information such the best alternative to be followed in order to reach an important destination. A used case for this, it is a driver who is traveling in the port direction. Near the place where some alternative ways/ decisions can be taken in order to reach the port area we place a virtual Vms. The informative content is managed by Strategy Manager who analyze travel times and other available data (i.e. buffer parking availability data…) to expose the best informative content.

As a first step, the critical hours and critical zones must be identified, and after this the idea is to transmit to the shipping companies that the road capacity of the port's surroundings is on the verge. In this way, camion's drivers can wait in the zones destined as buffer zones. Pinna, as said before, introduced four possible buffer zones that are distributed all around Trieste:

- Cervignano with 125 slots and located 64 min away from Trieste
- Gorizia with 550 slots and located 54 min away from Trieste
- Monfalcone with 81 slots and located 44 min away from Trieste
- Fernetti with 200 slots and located 26 min away from Trieste

In this way, the traffic will not be congested in the same zone simultaneously but will be distributed along the day, improving the overall throughput of the system, solving the critical waiting times and the often traffic jam.

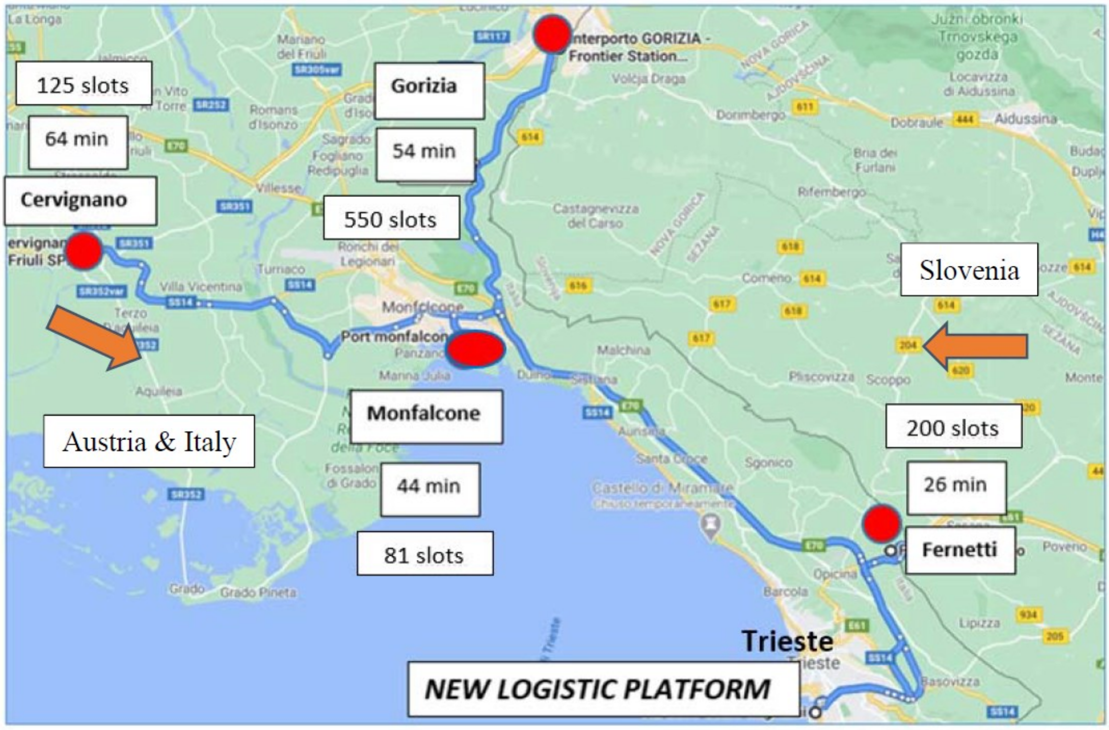


Figure 47. The four identified parking buffer areas (Pinna, 2021)

- The second solution is a more forefront option consisting of a route advice system carried out through an app that would keep updated more individual way for each heavy vehicle driver. This solution is more complex than the first one, and its development brings with it a more structured process. To do so, it must be present the report of the fleet management, terminal use specifications (capacity, function, schedules, level of saturation), a constant traffic monitoring that can be done through sensors, and a structured model that can simulate the future behavior of the port and the inland activity (an Arena model for example) in order to predict the critical events that may occur. All this information would be translated into a series of warnings and messages that would redirect the traffic to avoid big waiting times and traffic jams.

  As Bonsall P. (1991) expressed, -who studied the influence of route guidance advice on route choice in urban networks, addressing the impact of in-vehicle route guidance and information (IVRGI)- the challenge is to know how the route choice process and behavioral constructs are modeled. It was evidenced that most drivers received guidance selectively, and their response is conditioned by the quality of the information and the existence of any corroborating or conflicting evidence.

Given the second option's complexity, to simplify the modeling process in this Master Thesis, the first option was chosen to be simulated. For the current system it was hypothesized a series of restrictions that are going to be enlisted:

- For the light vehicles, the initial conditions remained since the application of restrictions to the public users is complicated and might bring conflict of interests.

- For the private heavy vehicles traffic, related to the port, the transit in the peak hours was forbidden, and this flow was distributed rearranging the heavy vehicles O/D matrix of the most problematic scenario (scenario 3), in this way, the idea was to have the same quantity of flow but better distributed.

Table 19. O/D distribution for the local broadcast solution.

HOURS	Third scenario (% of O/D matrix)	Fourth scenario (% of O/D matrix)	DESCRIPTION
1	30%	30%	PRE PEAK HOUR
2	100%	0%	PEAK HOUR
3	60%	60%	POST PEAK HOUR
4	40%	60%	INTERMEDIATE HOUR
5	40%	60%	INTERMEDIATE HOUR
6	40%	70%	INTERMEDIATE HOUR
7	40%	70%	INTERMEDIATE HOUR
8	40%	70%	INTERMEDIATE HOUR
9	40%	70%	INTERMEDIATE HOUR
10	40%	60%	INTERMEDIATE HOUR
11	40%	60%	INTERMEDIATE HOUR
12	60%	60%	POST PEAK HOUR

13	100%	0%	PEAK HOUR
14	30%	30%	POST PEAK HOUR

In a real-life scenario, this configuration would be implemented by using the Strategy manager SWARCO tool software. In order to configurate the software, the first step is to define the strategies; in this case the strategy consists in the emission of warnings messages through the VMS system to the user when the system is saturated, in this way the driver will know that the system has reached its maximum capacity and it will be suggested a buffer parking zone for the driver to wait until the system is decongested.

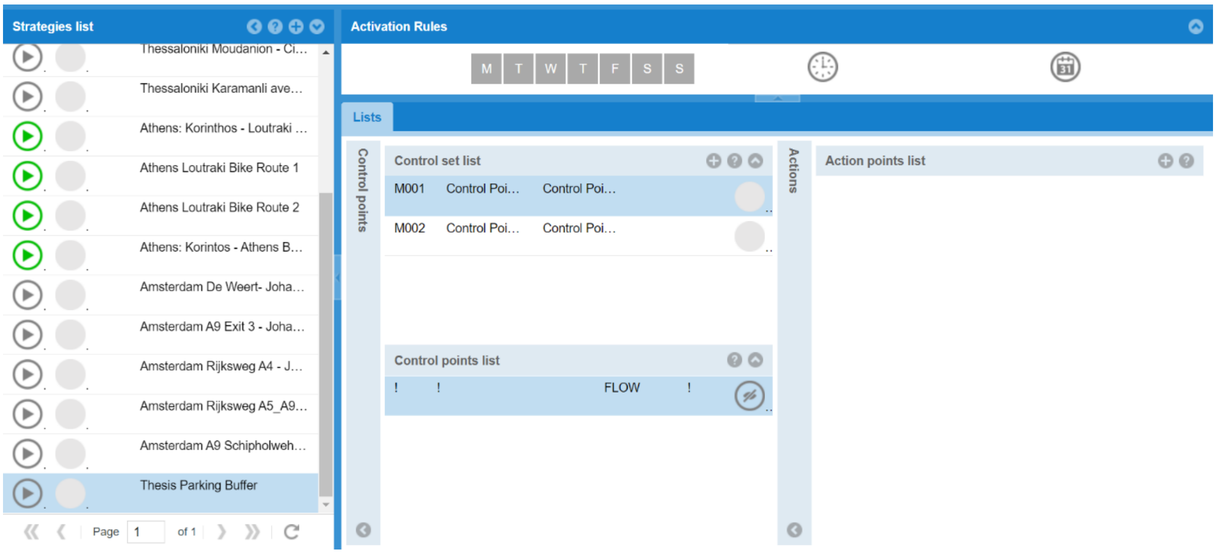


Figure 48. Strategy manager layout - Strategies definition

For this strategy two control point were configurated, one for each main flow sense. In the following figure are indicated the control point positions for the system.

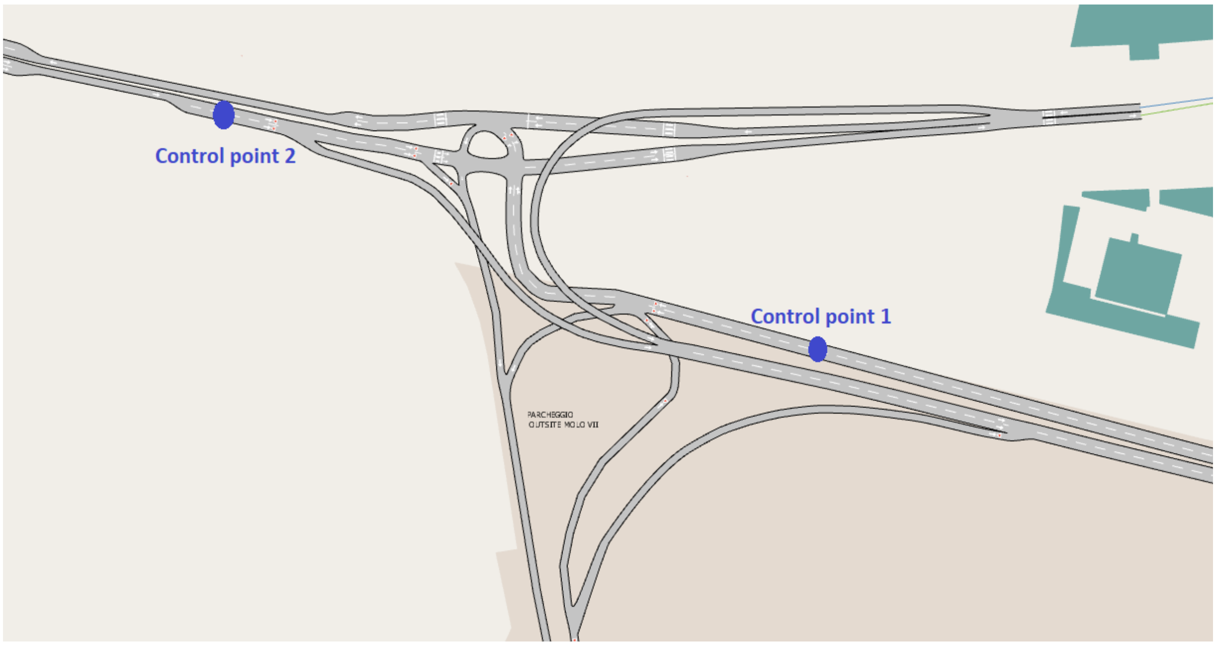


Figure 49. Control point's configuration

Once the control points are set, it is time to select the action points that will activate the strategy. In the following figures is shown the layout for the configuration of the action point and the selection of the sensor that will be implemented in each control point.

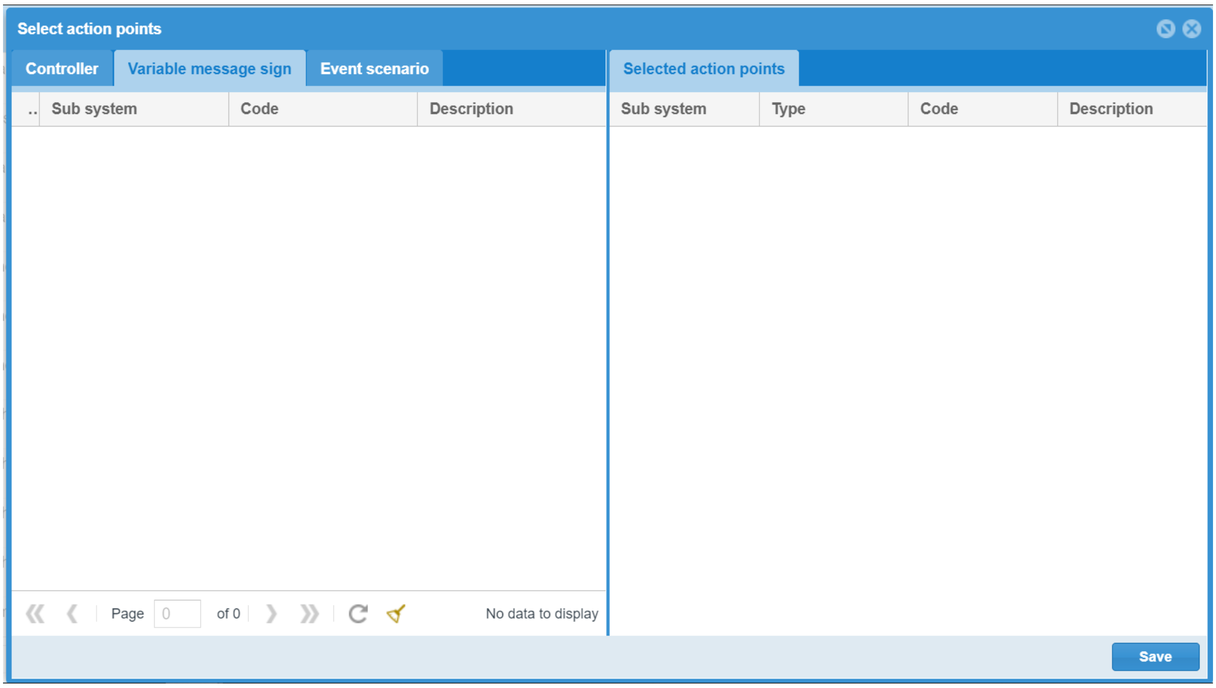


Figure 50. Strategy manager layout – action point's selection

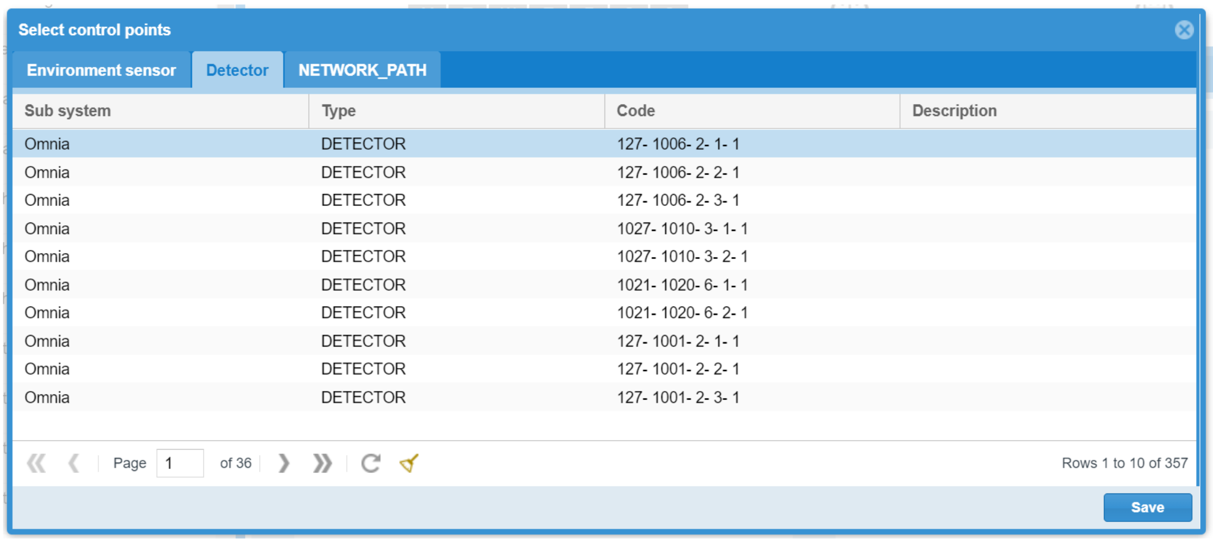


Figure 51. Strategy manager layout - sensor's selection

Once the sensor is selected, it is time now to indicate the measure indicator, this parameter is going to help us to activate the strategy. In this case the flow is selected, as shown in *Figure 52.* Strategy manager layout – service function, as a function parameter; it means that for each control point is going to be determine a limit value of flow and when this value is reached, the strategy will be activated.

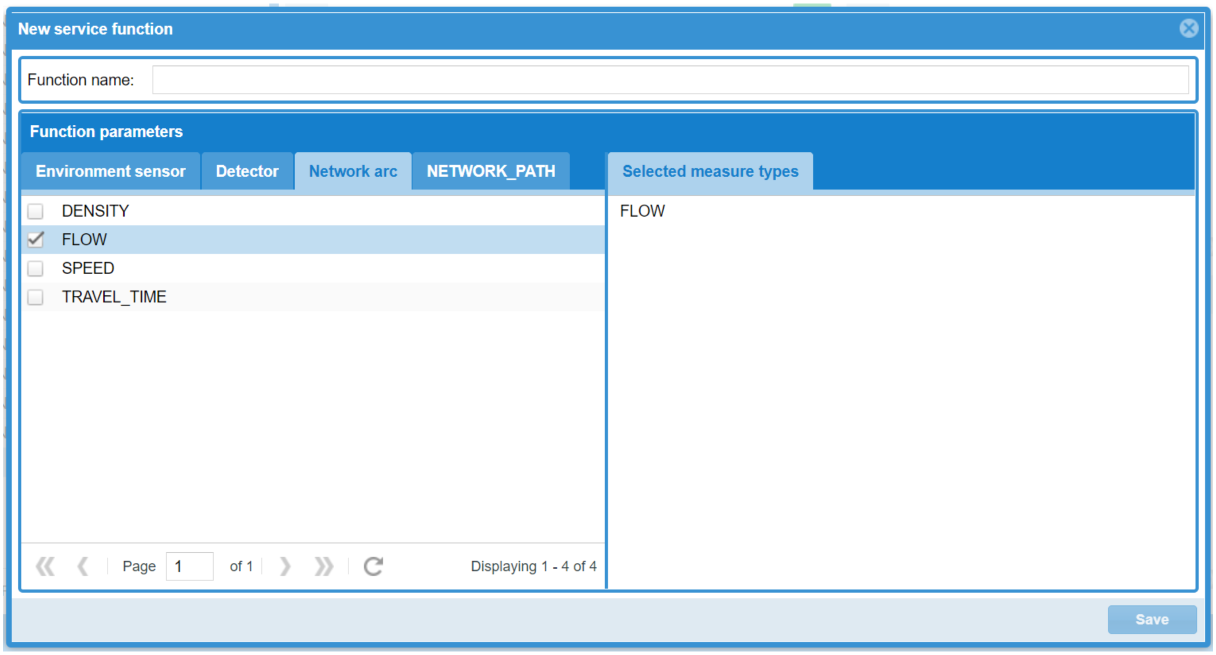


Figure 52. Strategy manager layout – service function

For control point 1 the flow limit value was set as 500 veh/h and for control point 2, 450 veh/h. When the system overpasses this value, the strategy would activate, and the tool will send a notification to the driver warning them that the system has reached the limit values and they might wait in the buffer parking zones. To do so, the information of each buffer zone's capacity is also required sharing with the user the parking availability, being another measure indicator;

in case there is no capacity over, the system will not recommend the user to stop in that buffer aerea. Once the sensor detect that the flow is under the limit values, it will send another notification to the user specifying that they can now enter to the network. In Figure *53*, is shown the service configuration and in Figure *54* is exhibited the physical VMS position.

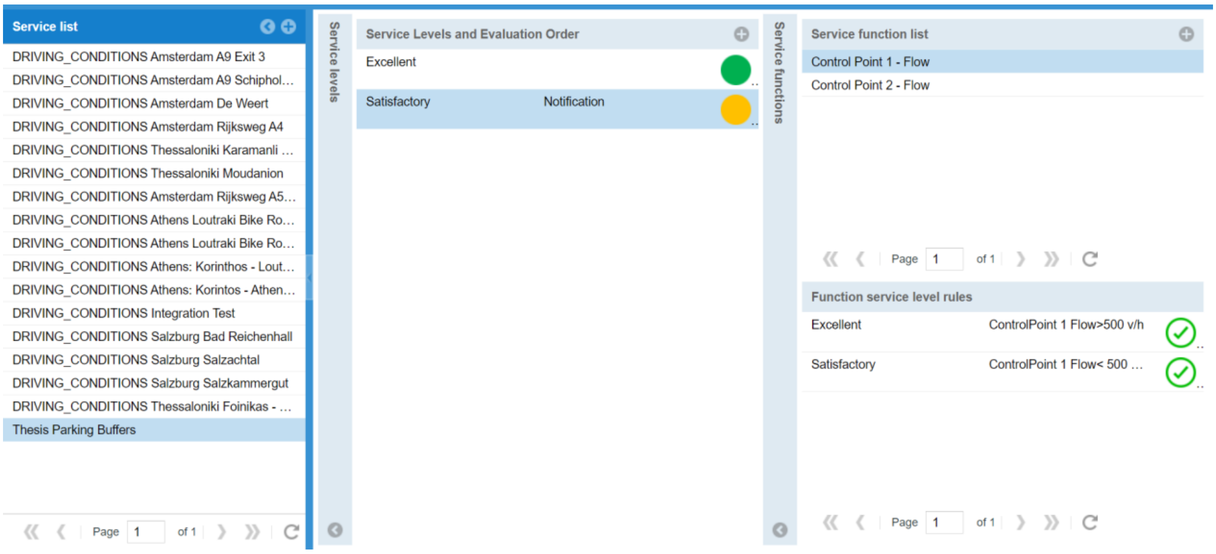


Figure 53. Strategy manager layout – service configuration

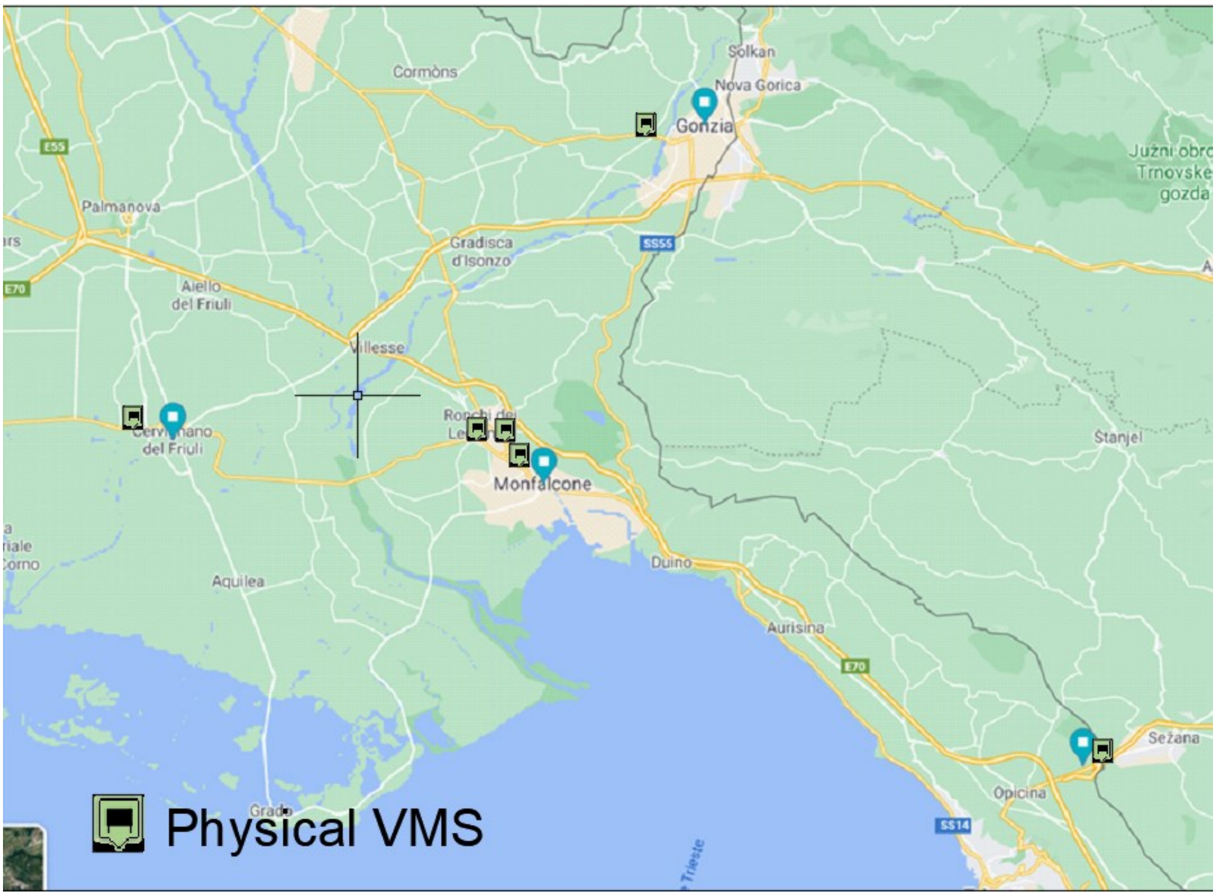


Figure 54. VMS panels position map

5. Results discussion

5.1. Scenario 1 – Initial conditions

After the definition of the scenarios, each matrix was a load to the respective traffic demand configuration. In this way, for the first scenario, a total number of 5 replications were set, and a final average replication was then calculated. With this kind of arrangement, the objective is to give the results a better statistical congruency to evaluate different simulations of the same framework in an average final result. The first step is to verify the compliance of the model with the objective conditions, to do so it has been considered the information given by the Piano Regolatore Portuale (Regulation port's plan) of Trieste in which are reported the TGM provided by ANAS, Direzione Centrale Lavori of an essential segment of the studied motorway SS202,

Table 20. TGM of SS202 - Santa Croce (Piano Regolatore Portuale di Trieste)

SS 202 - Santa Croce

TGM diurno	*14.450*
TGM notturno	4.642
TGM totale	*19.092*

Considering that our model is run from 7:00 to 20:30, the TGM diurno (diurnal) was selected as a referent parameter to verify the model. In the following table are presented the report of the parameters generated by AIMSUN regarding the input cars,

Table 21. Input count for scenario 1

DESCRIPTIONS	VALUE	UNITS
Input Count - All	13473,6	veh
Input Count - Car	13127,4	veh
Input Count - Truck	346,2	veh

It can be seen that knowing that this model was done with the data provided by Trieste municipality, it is concordant with the natural conditions reported by the Piano Regolatore Portuale in 2011 having around the same magnitude. Figure 56, Figure 57, Figure 58, and Figure 59 are shown the flow graph for each replication associated with this scenario.

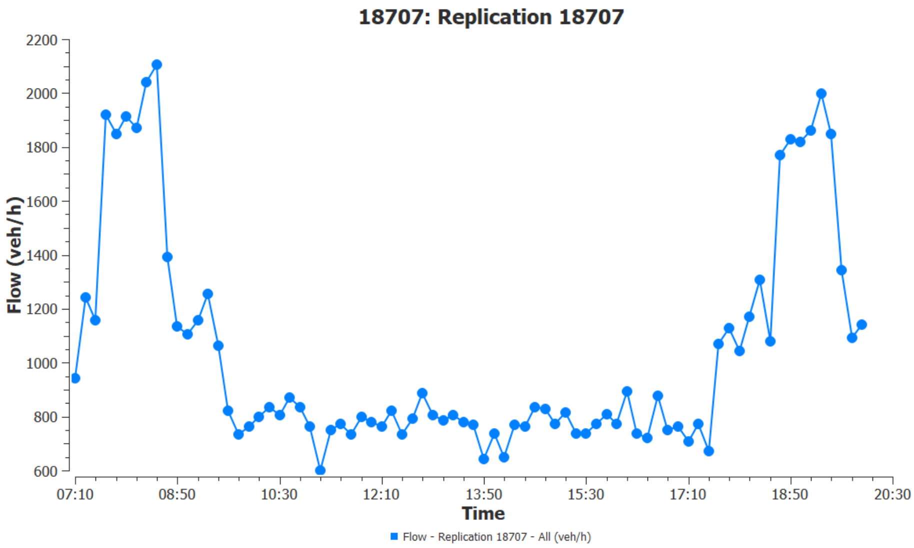


Figure 55. Flow graph: Scenario 1, replication 1

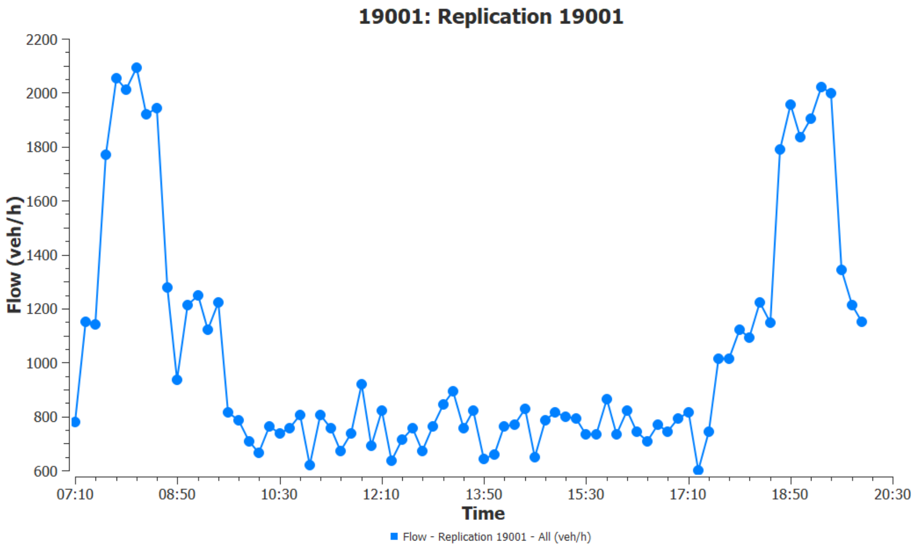


Figure 56. Flow graph: Scenario 1, replication 2

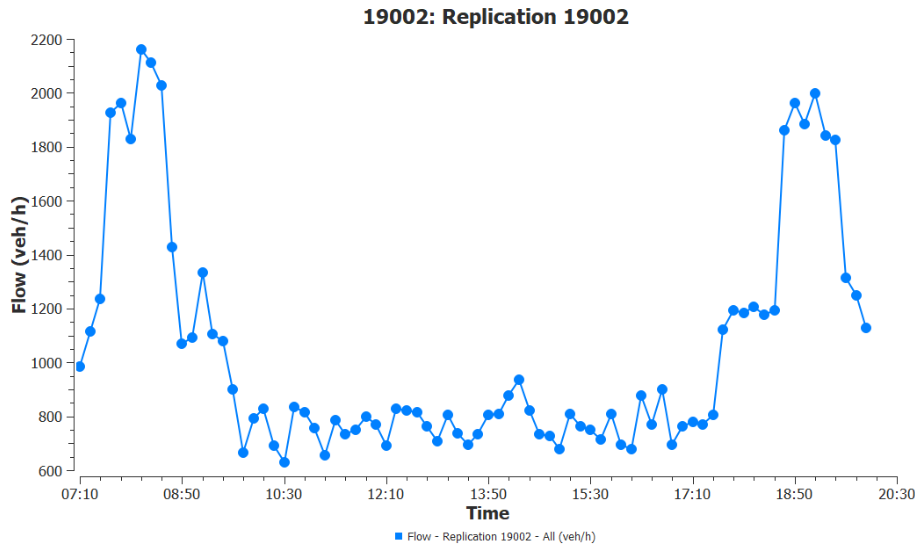


Figure 57. Flow graph: Scenario 1, replication 3

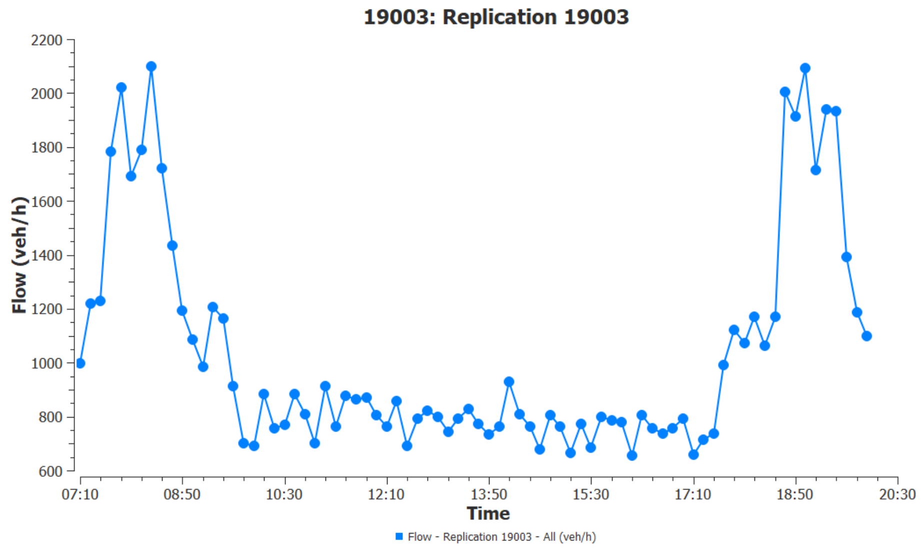


Figure 58. Flow graph: Scenario 1, replication 4

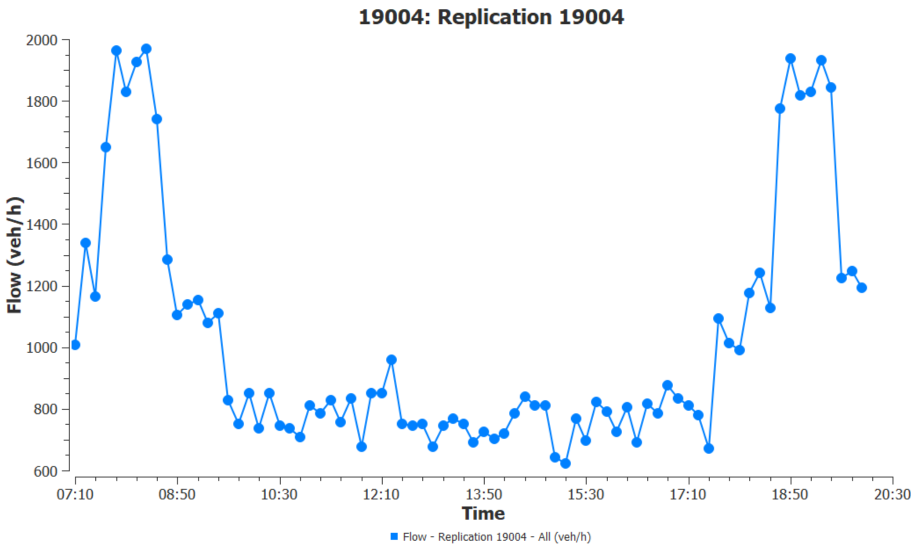


Figure 59. Flow graph: Scenario 1, replication 5

Finally is reported the flow average graph associated with scenario 1.

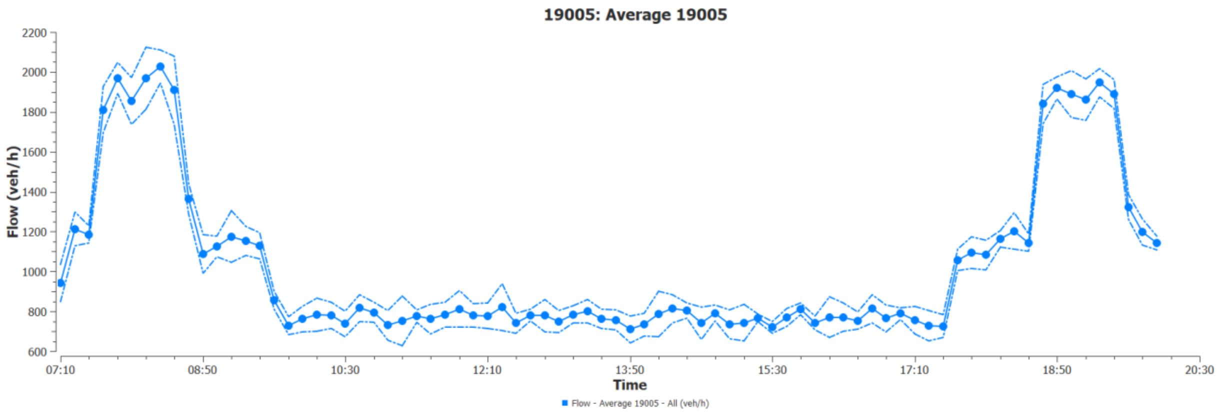


Figure 60. Flow average graph scenario 1: Repl. 1 (18707), Repl. 2 (19001), Repl. 3 (19002), Repl. 4 (19003), Repl. 5 (19004)

Analyzing the average flow graph, it is notorious that the flow behaves expectedly, reaching the maximum values in the morning and afternoon peak hours. The maximum flow value is 2034 veh/h reached at 08:20 ubicated in the first peak hour. Concerning the second peak hour, we find a maximum value of 1951 veh/h reached at 19:20. The following figures documented the delay time graph for each replication and the final average regarding the delay time.

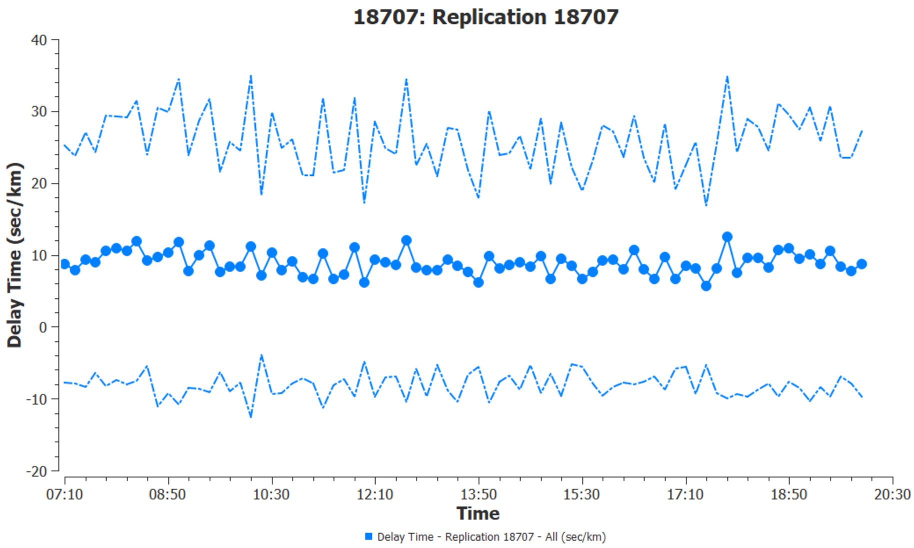


Figure 61. Delay time graph: Scenario 1, replication 1

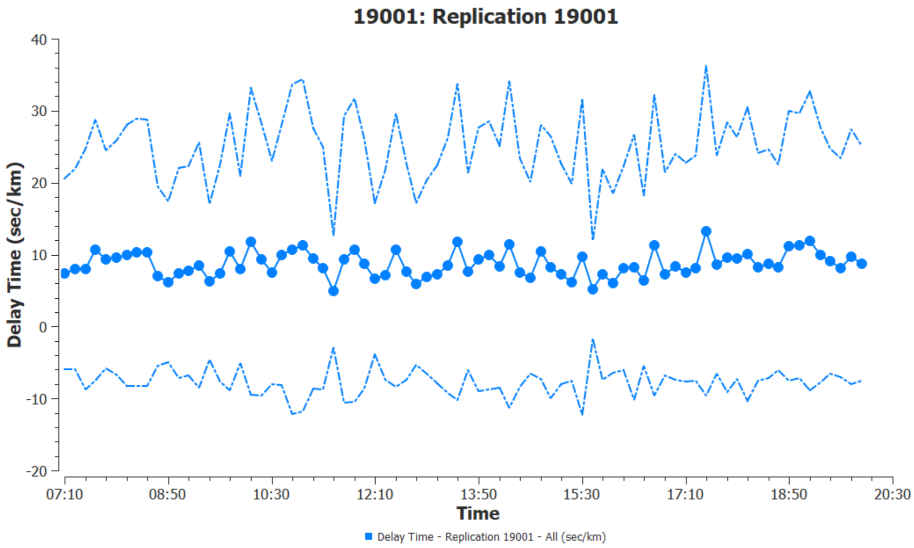


Figure 62. Delay time graph: Scenario 1, replication 2

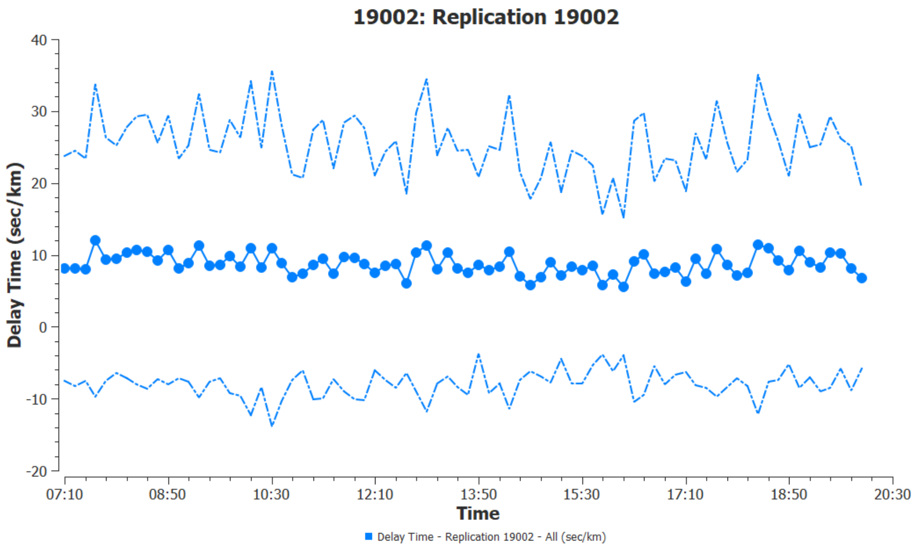


Figure 63. Delay time graph: Scenario 1, replication 3

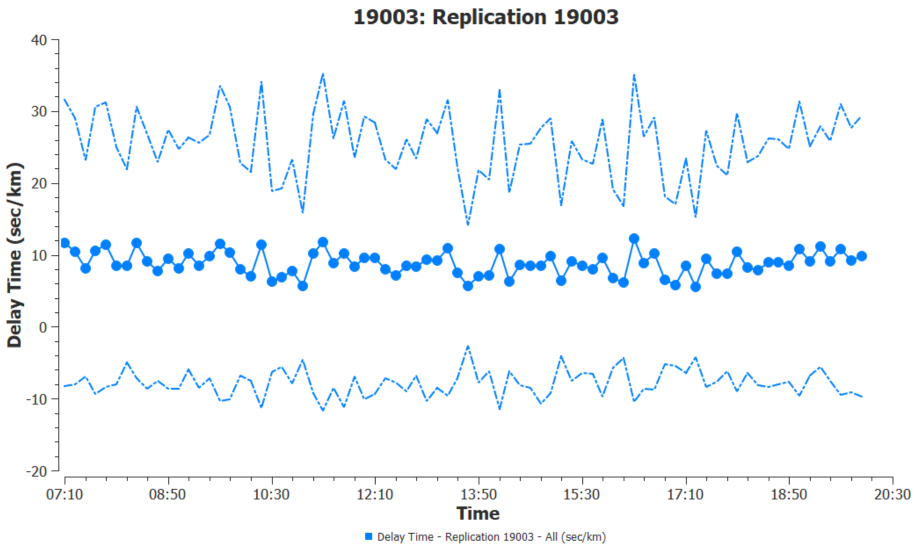


Figure 64. Delay time graph: Scenario 1, replication 4

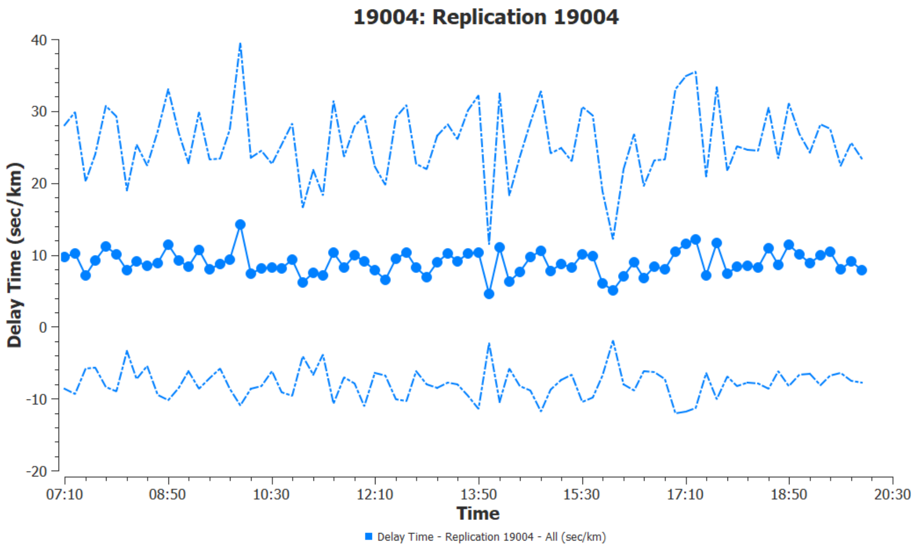


Figure 65. Delay time graph: Scenario 1, replication 5

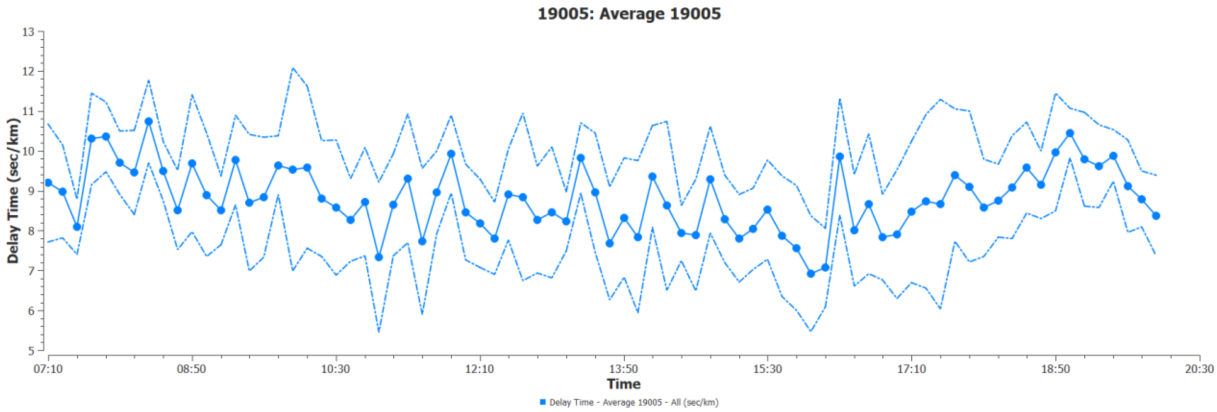


Figure 66. Delay time average graph scenario 1: Repl. 1 (18707), Repl. 2 (19001), Repl. 3 (19002), Repl. 4 (19003), Repl. 5 (19004)

As it can be observed, the behavior of the delay time is relatively constant. We can see an average variation between 6,9 sec/km to 10,8 sec/km, which does not represent a big problem and reflects the conduct of a system that does not have critical problems. The following graphs will be shown the performance of the speed graph by replication and, as done with the previous parameters, the average one.

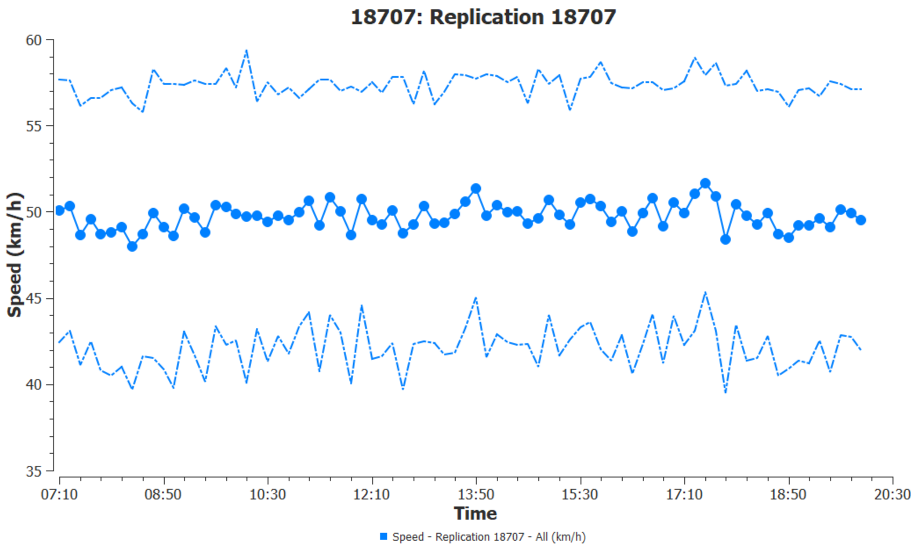


Figure 67. Speed graph: Scenario 1, replication 1

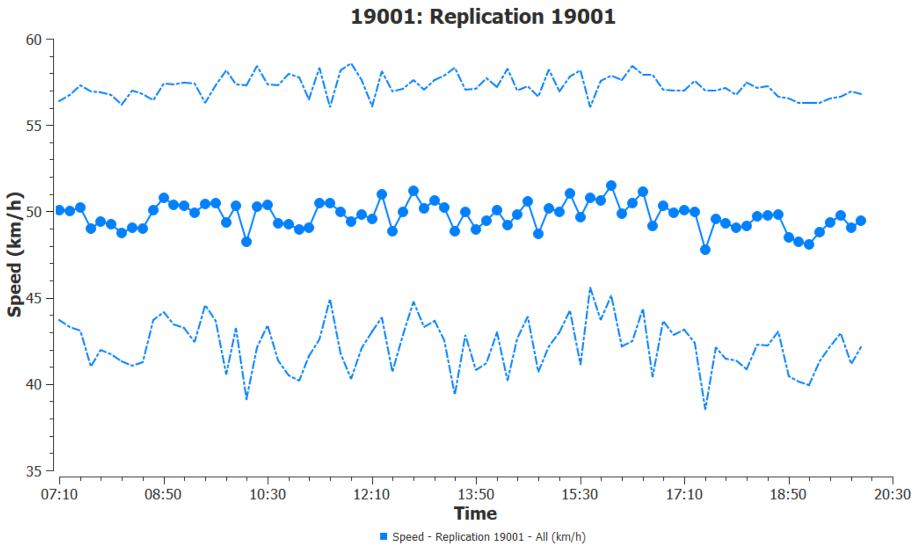


Figure 68. Speed graph: Scenario 1, replication 1

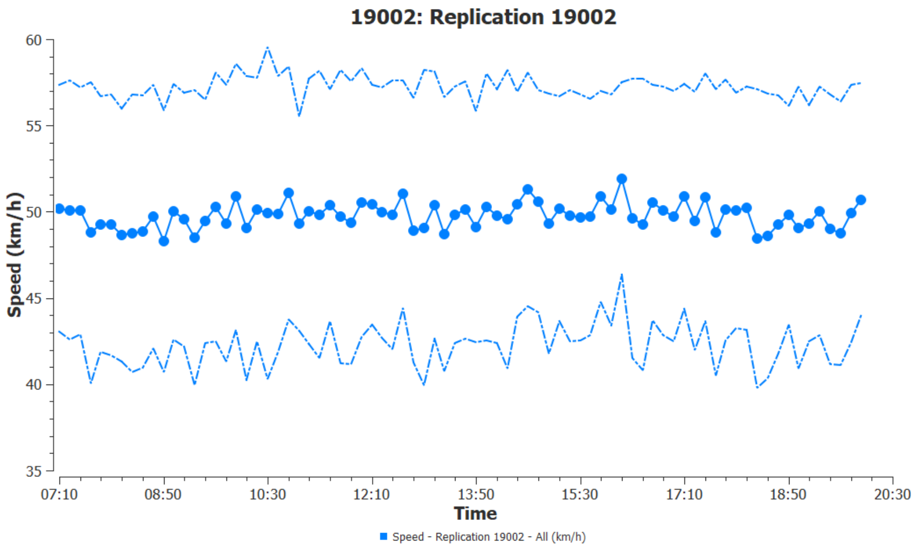


Figure 69. Speed graph: Scenario 1, replication 3

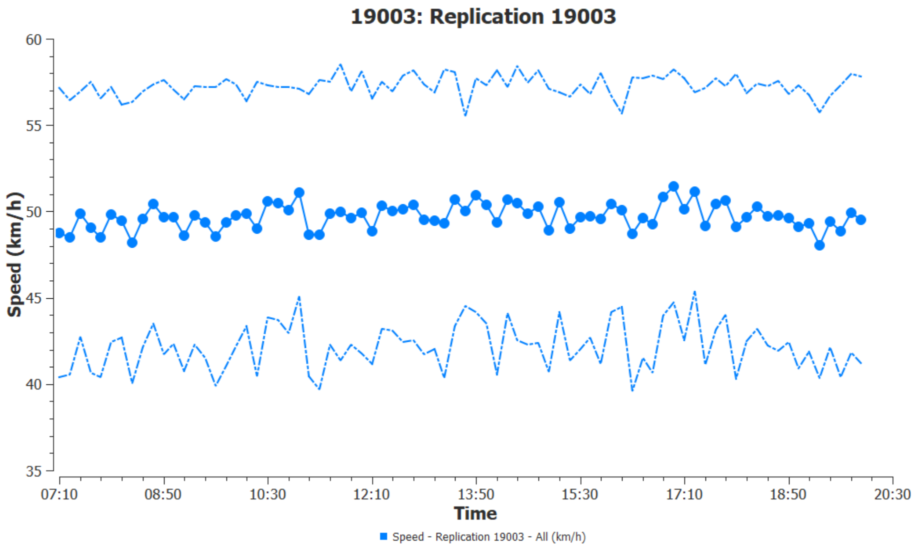


Figure 70. Speed graph: Scenario 1, replication 4

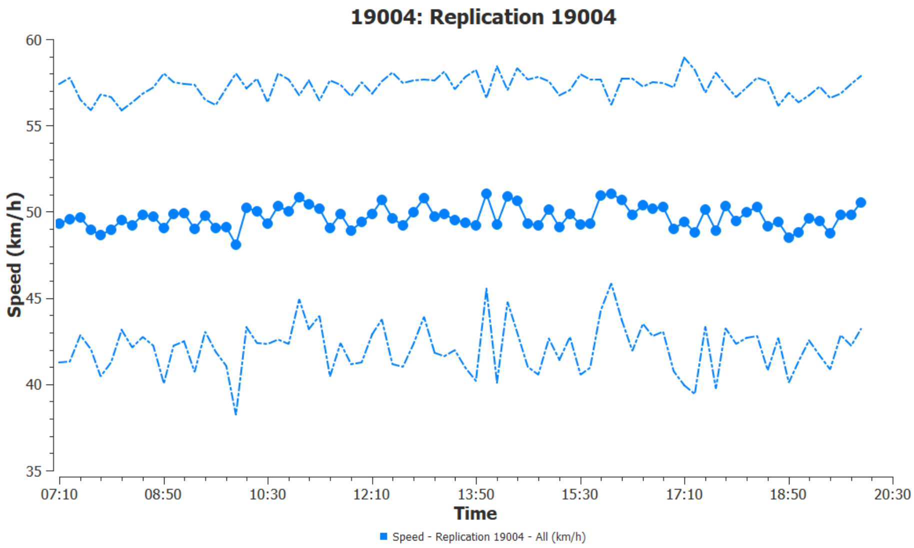


Figure 71. Speed graph: Scenario 1, replication 5

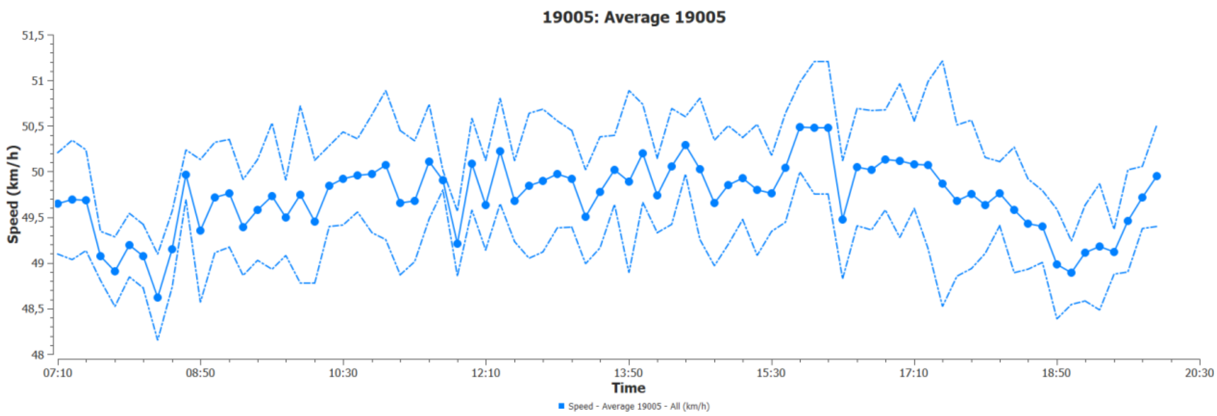


Figure 72. Speed average graph scenario 1: Repl. 1 (18707), Repl. 2 (19001), Repl. 3 (19002), Repl. 4 (19003), Repl. 5 (19004)

As expected, and in concordance with the tendency of the waiting time, the speed shows a constant behavior. The average graph can notice a slight decrement in the peak hours, but it does not evidence a critical scenario keeping the entire simulation a velocity between 48,5 km/h to 50/5 km/h.

5.2. Scenario 2 – 2011's traffic inland situation generated by the port

Following the same procedure used for the first scenario, the same number of replications were used. In this case, bearing in mind that the congruence analysis for the first scenario was done, and this scenario was based on the same conditions as the first one, it was decided to evaluate the congruence in this way. Taking as a parameter the flow generated by the port expressed in the PRP of Trieste where it is reported that the port generates flows of around 4000 vehicles, that would be traduced into 500 vehicles in the peak hour, it is possible to compare this value with the input count Truck generated by the model.

Table 22. Parameter scenario 2

DESCRIPTIONS	VALUE	UNITS
Input Count - All	17764,6	veh
Input Count - Car	13222,8	veh
Input Count - Truck	4541,8	veh
Input Flow - All	1366,51	veh/h
Input Flow - Car	1017,14	veh/h
Input Flow - Truck	349,37	veh/h

It can be observed that the model generates an input count of trucks equal to 4541,8 veh that follows the guidelines set by the PRP. In the following figures is shown the behavior of the different replications and the average one, where it can be seen an increment of total flow, as expected by the introduction of the volumes generated by the port, and it is to highlight that the maximum value is now 2600 veh/h reached, as contemplate, in the peak hours.

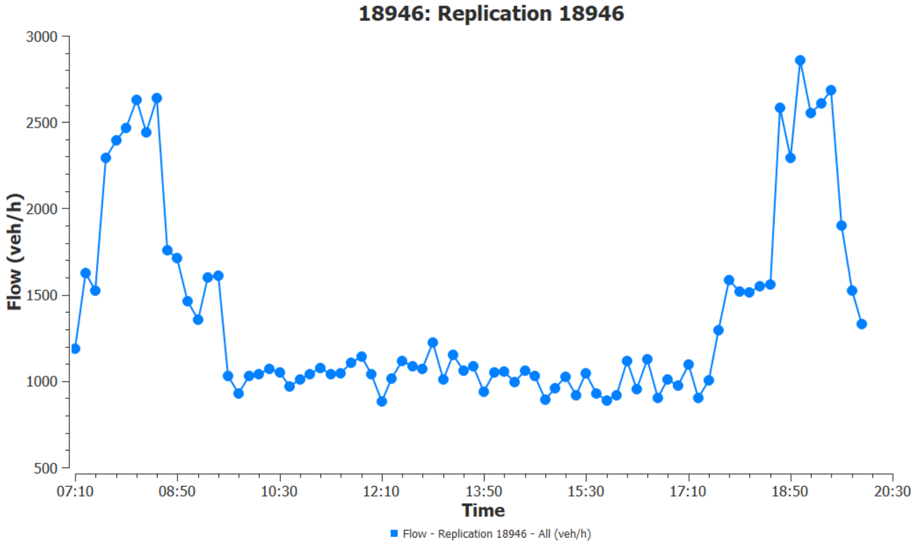


Figure 73. Flow graph: Scenario 2, replication 1

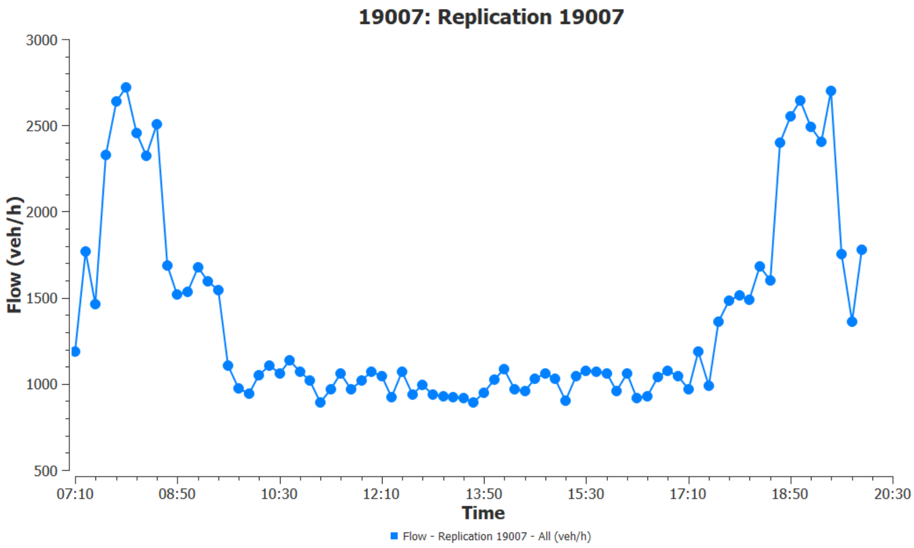


Figure 74. Flow graph: Scenario 2, replication 2

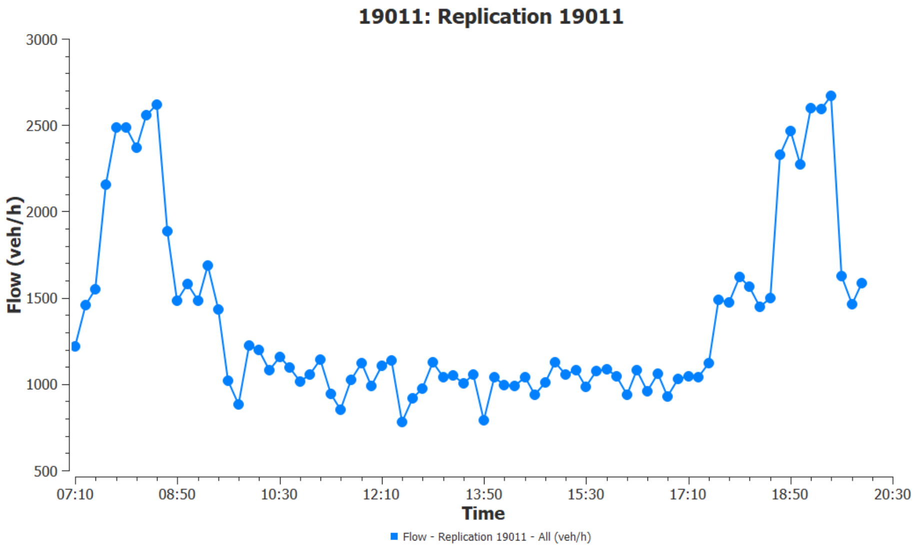


Figure 75. Flow graph: Scenario 2, replication 3

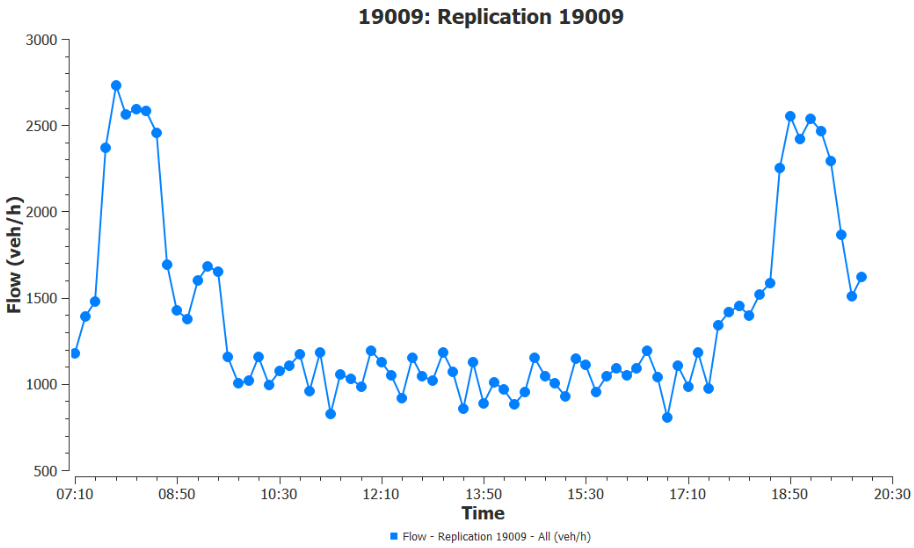


Figure 76. Flow graph: Scenario 2, replication 4

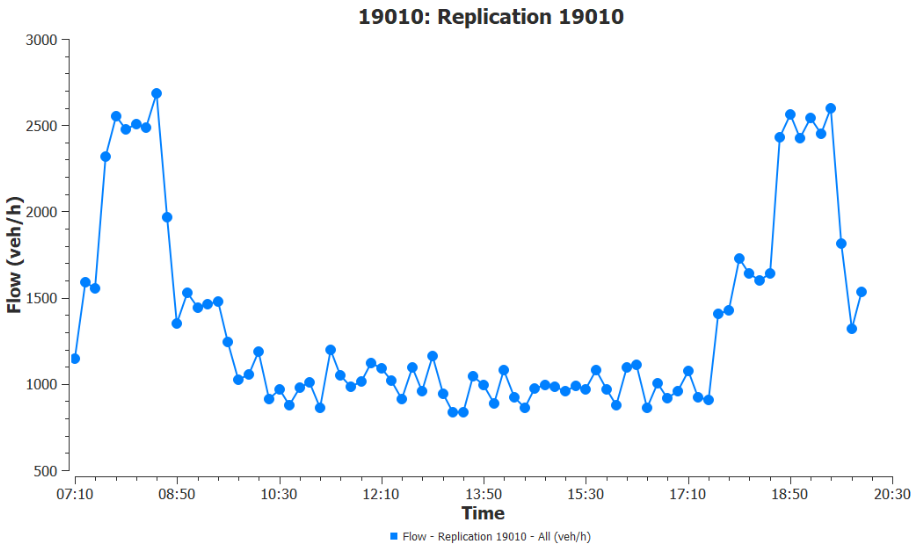


Figure 77. Flow graph: Scenario 2, replication 5

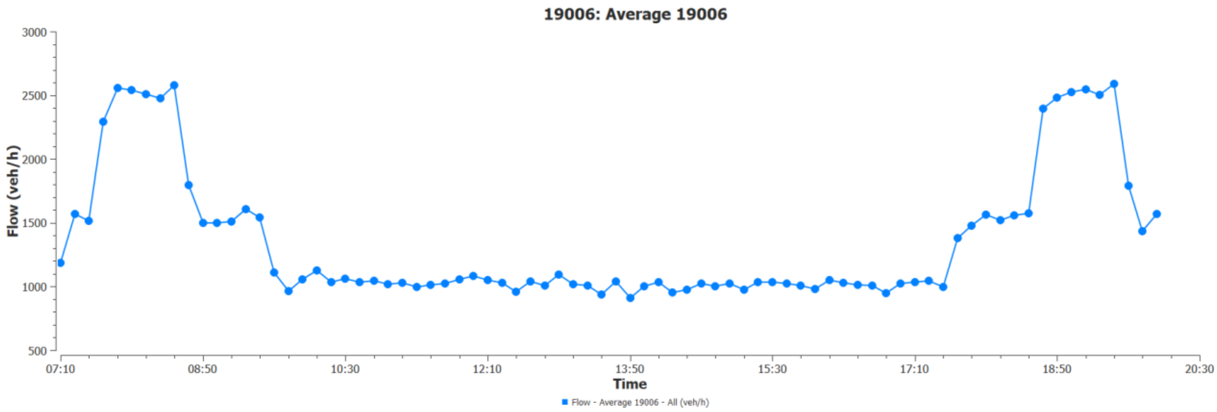


Figure 78. Flow average graph scenario 2: Repl. 1 (18946), Repl. 2 (19007), Repl. 3 (19008), Repl. 4 (19009), Repl. 5 (19010)

After analyzing the delay time's behavior, it can be seen that it had a critical increment, reaching values of almost 80 sec/km in some replications. We found out a total increment of around 82% compared to scenario 1, having as a referent value the total average delay time in the first one, being equal to 9.01 sec/km and 16.39 sec/km for scenario 2. In the average graph, the maximum value of delay time was equal to 41.5 sec/km representing a traffic problem, but it does not evidence the real problem that has been happening in the proximities of the port. This problem could be caused because the reference data date back to 2011, and the development of containership has had an essential increment since then.

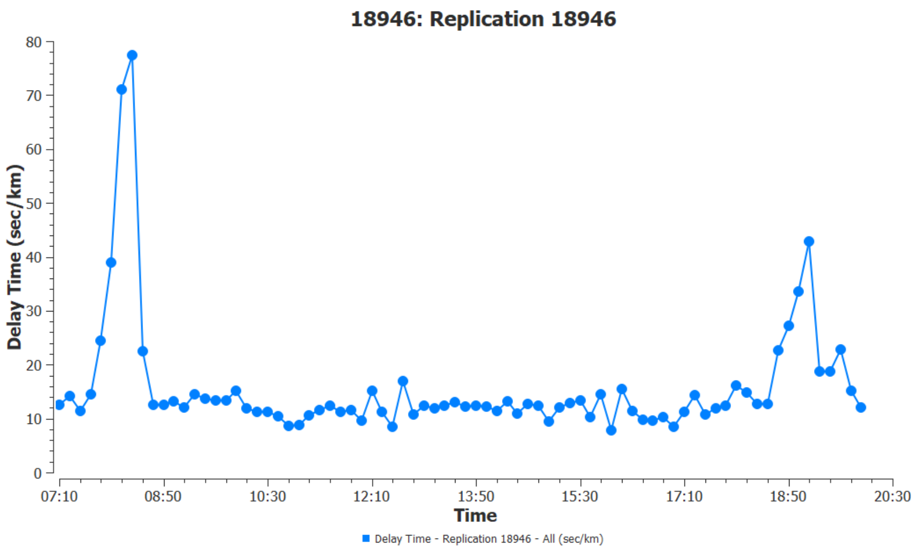


Figure 79. Delay time graph: Scenario 2, replication 1

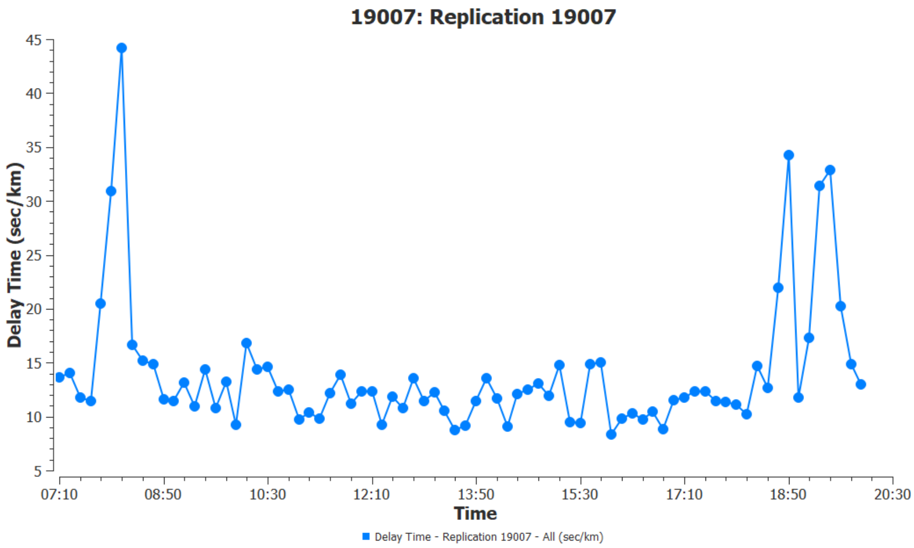


Figure 80. Delay time graph: Scenario 2, replication 1

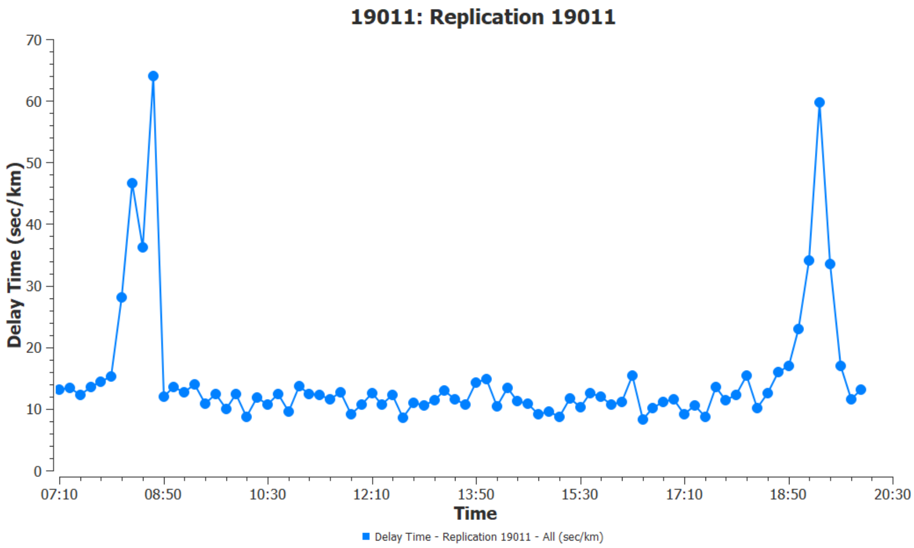


Figure 81. Delay time graph: Scenario 2, replication 3

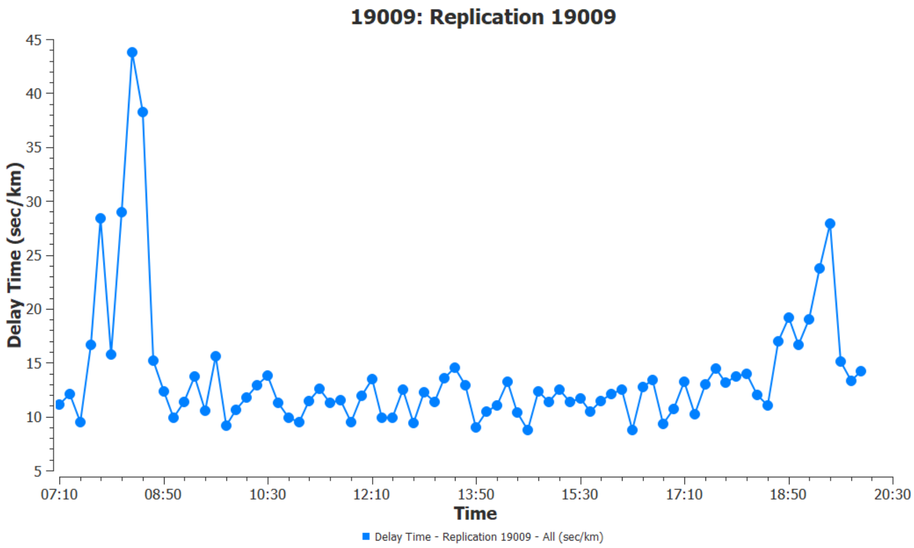


Figure 82. Delay time graph: Scenario 2, replication 4

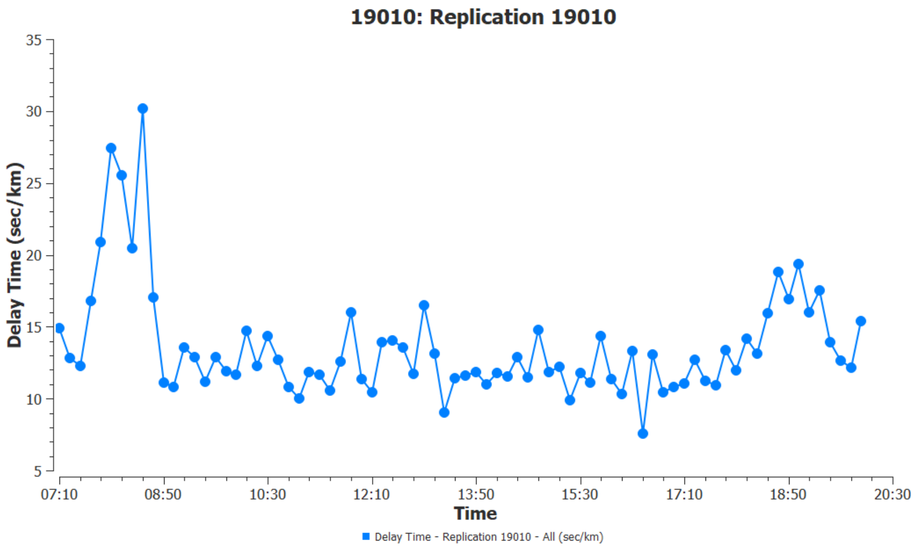


Figure 83. Delay time graph: Scenario 2, replication 5

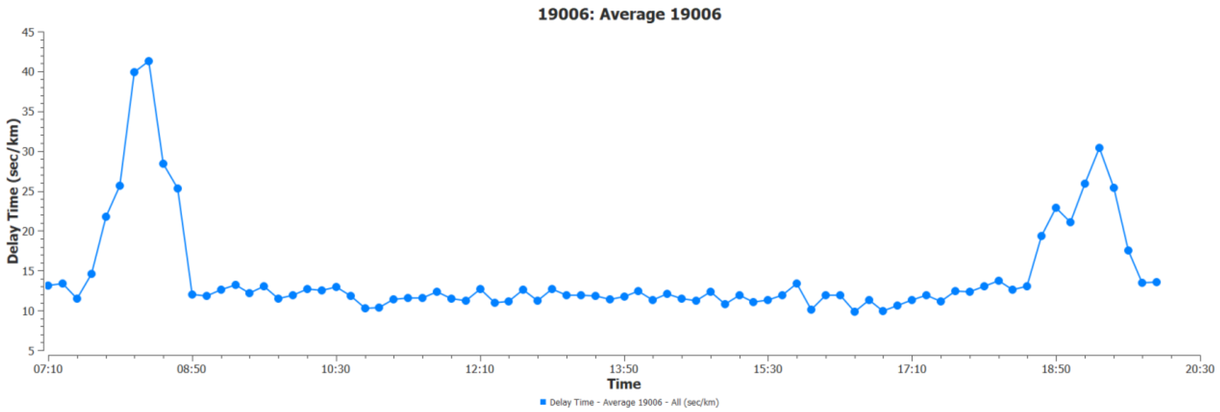


Figure 84. Delay time average graph scenario 2: Repl. 1 (18946), Repl. 2 (19007), Repl. 3 (19008), Repl. 4 (19009), Repl. 5 (19010)

As far as speaking of speed, the total system has a decrement of 5 %, but in the different replications, it was evident during the peak hours the present drop of speed, reaching values of 43 km/h. In the average graph, there was a minimum of 43.6 km/h that, compared to scenario 1, represents a decrement of around 5 km/h in the lowest value.

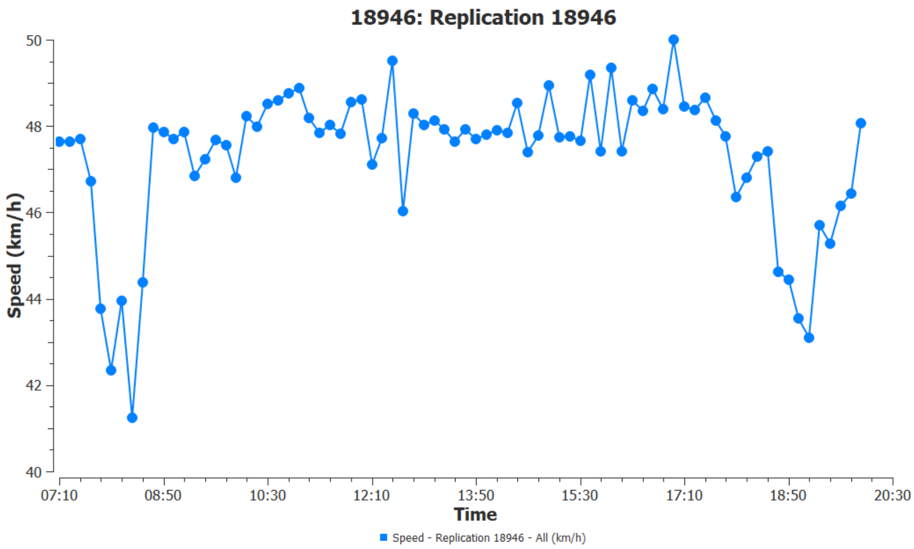


Figure 85. Speed graph: Scenario 2, replication 1

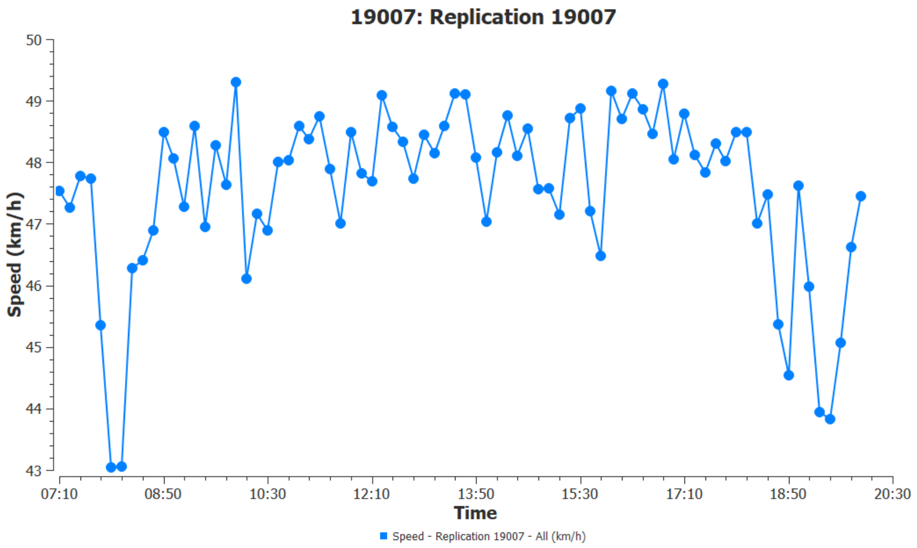


Figure 86. Speed graph: Scenario 2, replication 2

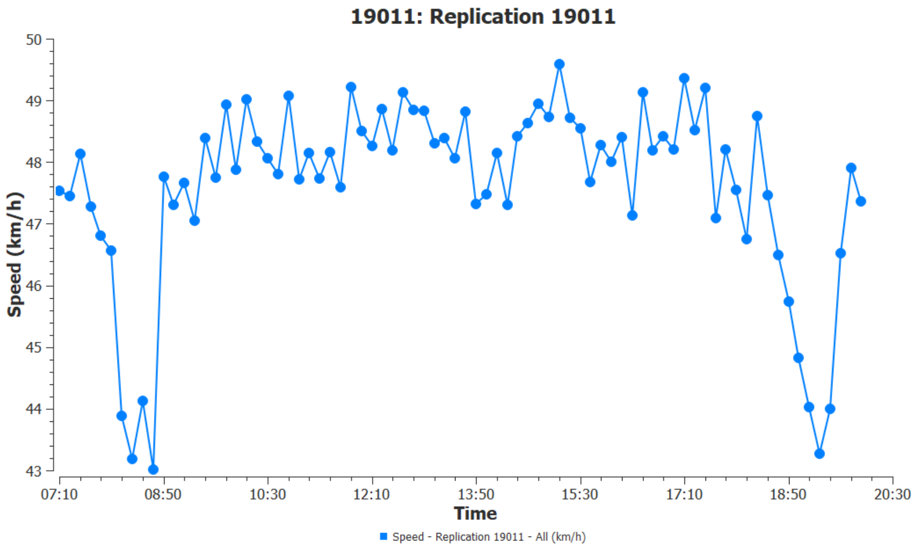


Figure 87. Speed graph: Scenario 2, replication 3

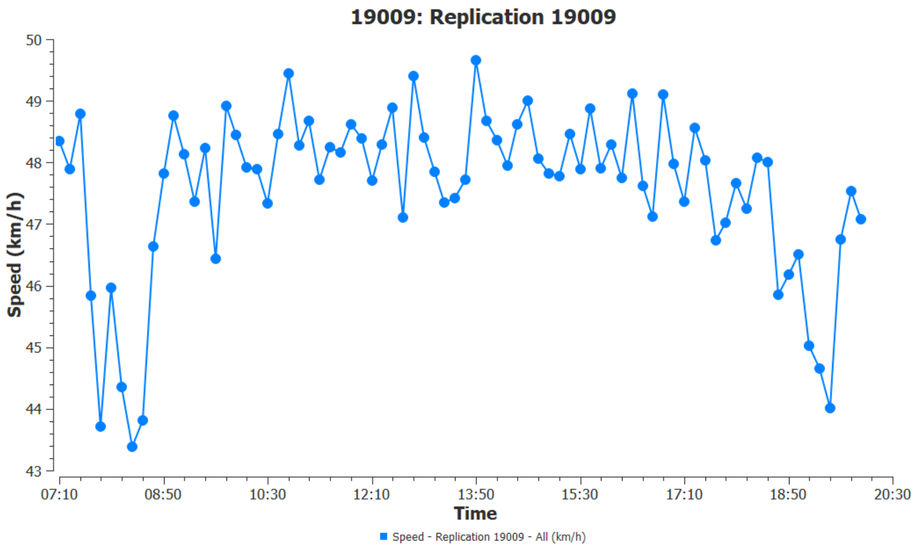


Figure 88. Speed graph: Scenario 2, replication 4

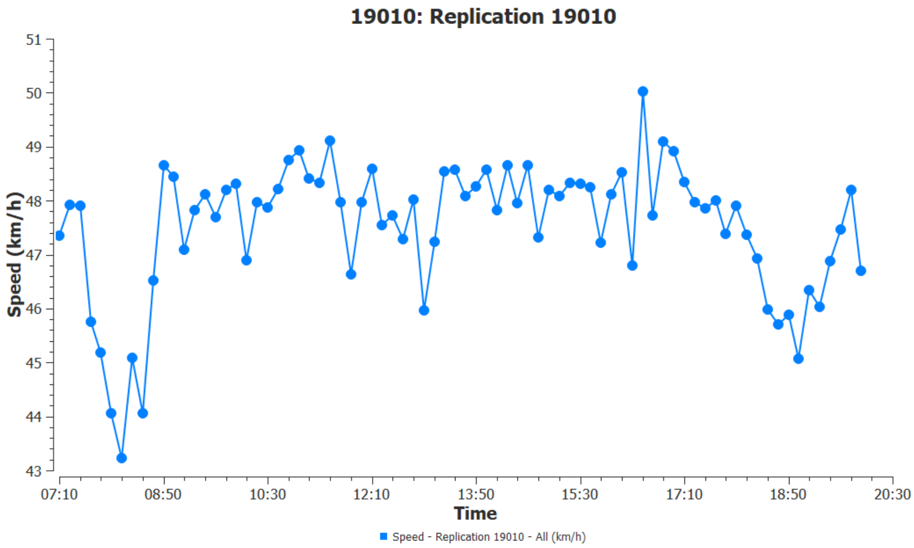


Figure 89. Speed graph: Scenario 2, replication 5

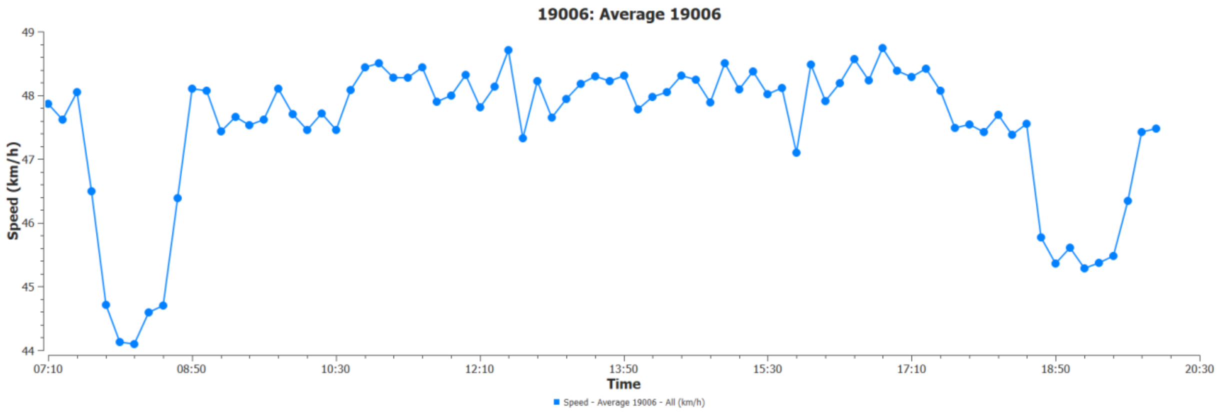


Figure 90. Speed average graph scenario 2: Repl. 1 (18946), Repl. 2 (19007), Repl. 3 (19008), Repl. 4 (19009), Repl. 5 (19010)

In comparison with scenario 1, it was already evident the formation of queues and the phenomenon of congestion. In Figure 91, it can be seen the queue that was generated in the peak morning hour and in Figure 92, it was shown the line developed in the peak afternoon hour. Neither of the two being present in the scenario 1.

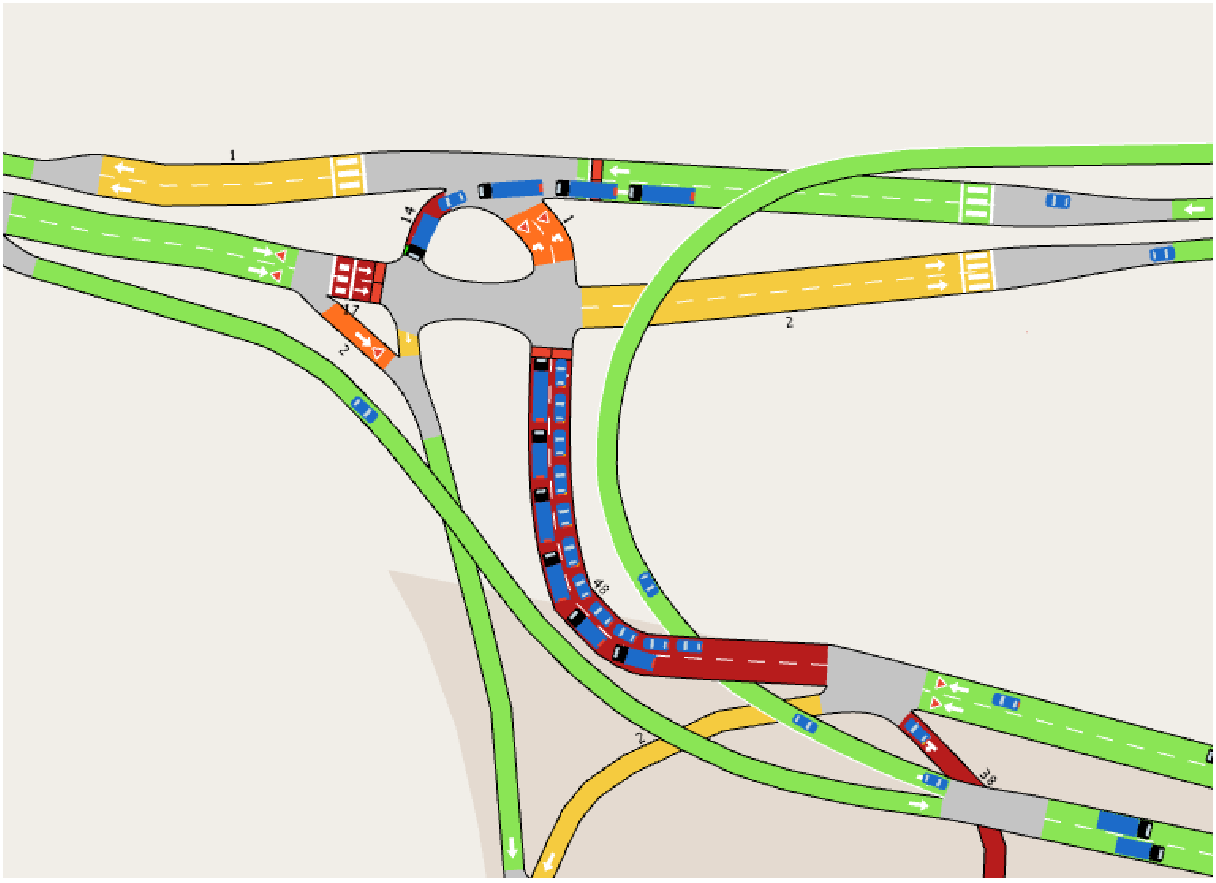


Figure 91. Software image of queue formation scenario 2 (1)

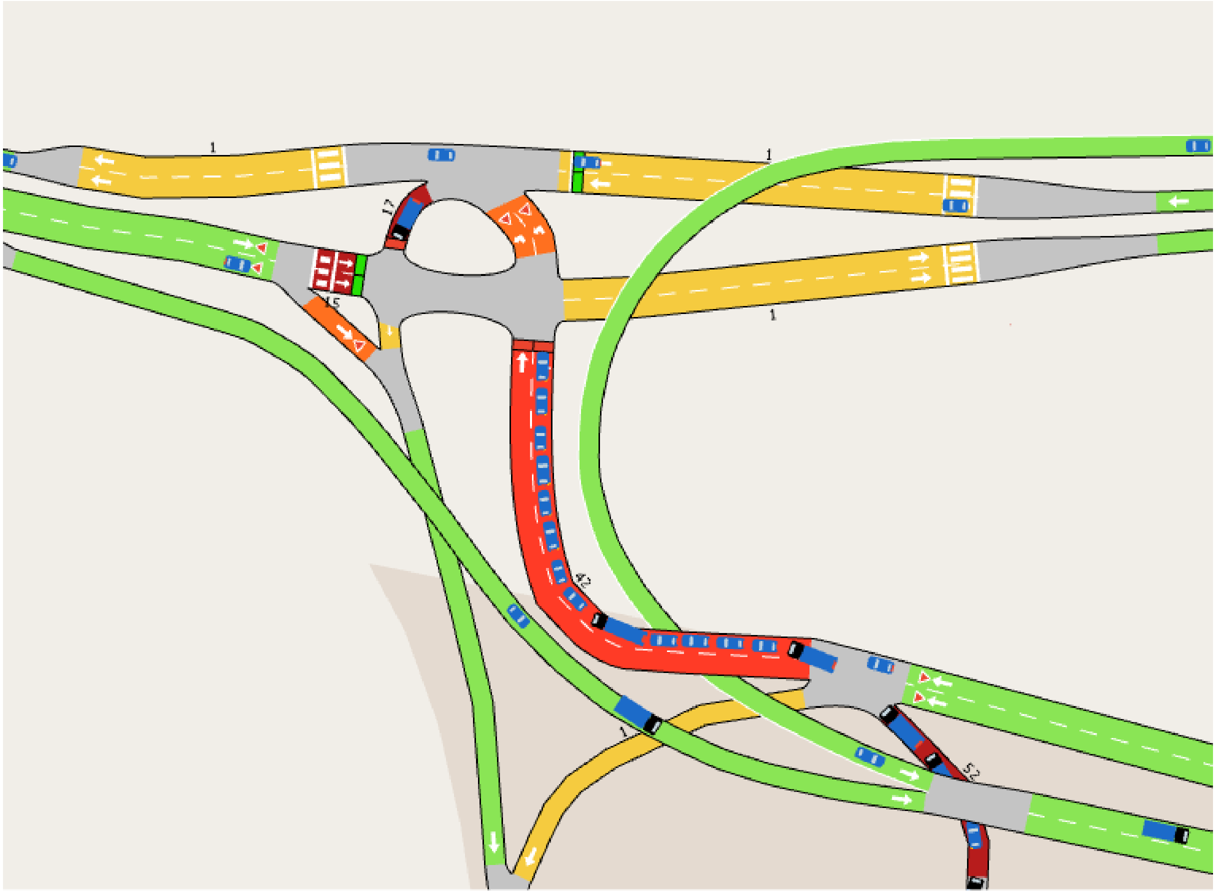


Figure 92. Software image of queue formation scenario 2 (2)

5.3. Scenario 3 – Containerships Gigantism consequences into inland traffic situation

For the third scenario, as expressed in the scenario description, it was introduced a 40% increment of the flow; this was done to generate attractive conditions that may simulate the actual situation experimented by the port's surroundings. The idea was to reflect how the increment of maritime traffic has affected the inland traffic in Trieste.

5.3.1. Scenario 3 A

As expected, the flow's graph keeps the precedent behavior but with more significant volumes. In the average flow graph, the maximum value reached was equivalent to 2903 veh/h but having values greater than 3000 veh/h in some replications.

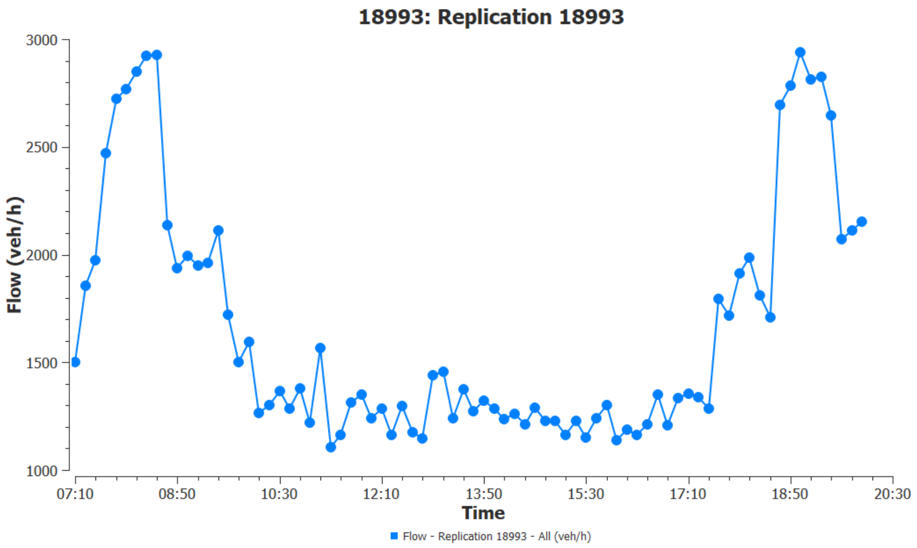


Figure 93. Flow graph: Scenario 3A, replication 1

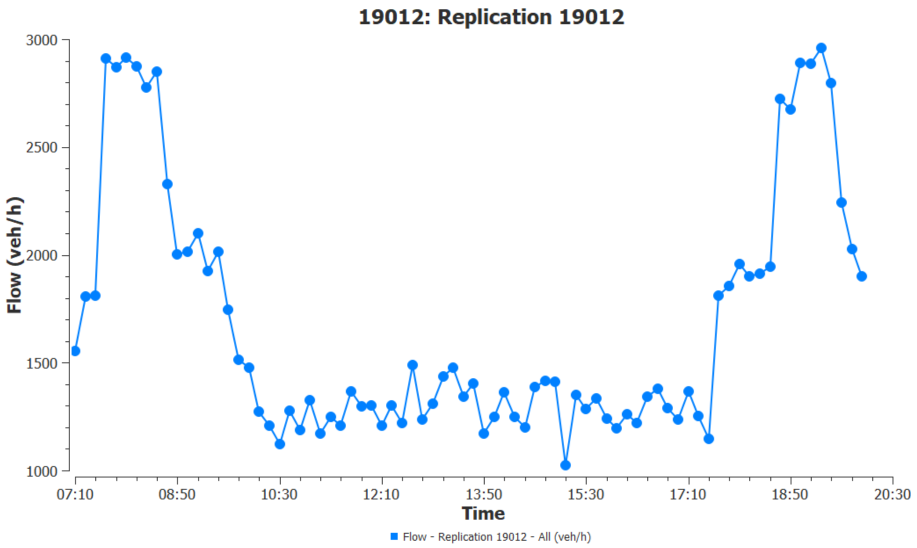


Figure 94. Flow graph: Scenario 3A, replication 2

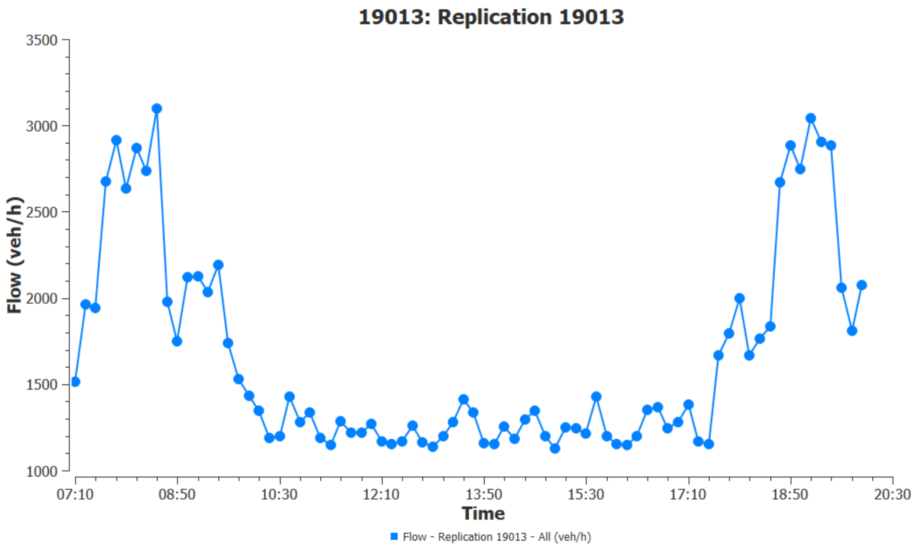


Figure 95. Flow graph: Scenario 3A, replication 3

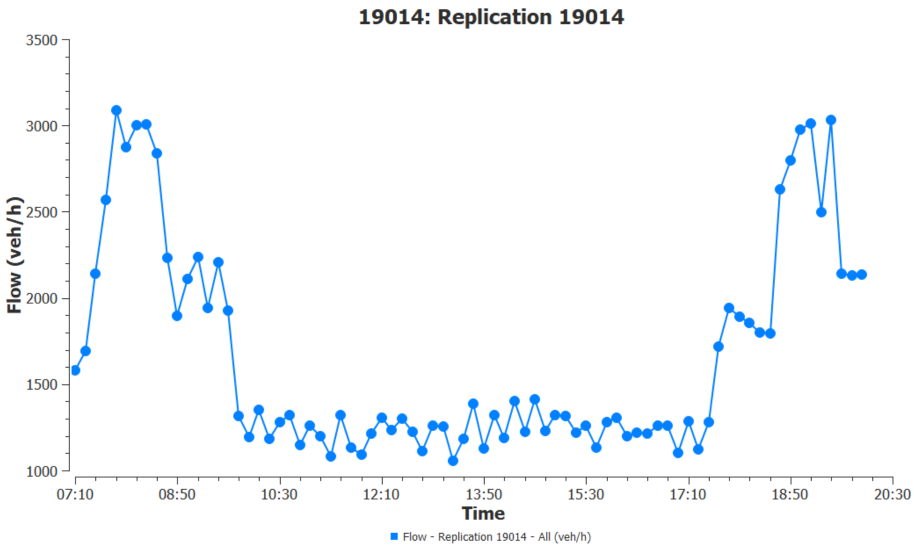


Figure 96. Flow graph: Scenario 3A, replication 4

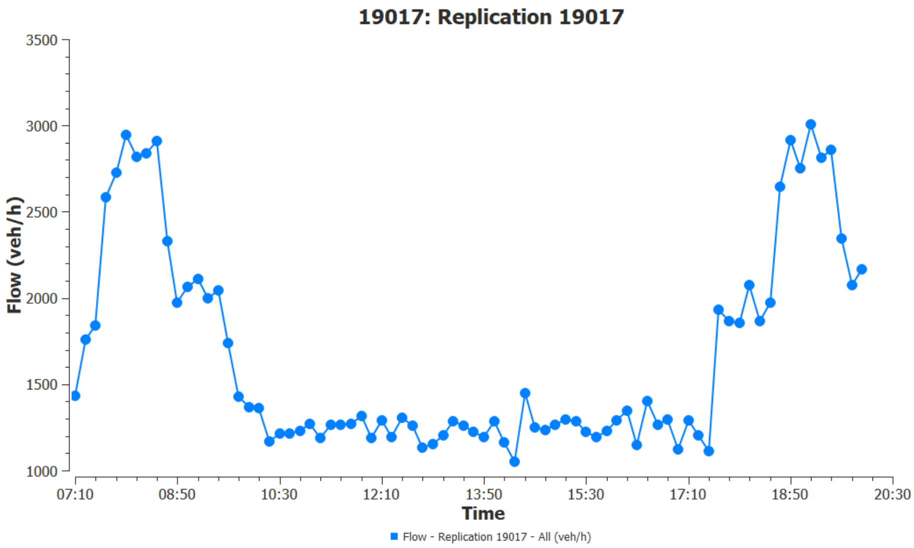


Figure 97. Flow graph: Scenario 3A, replication 5

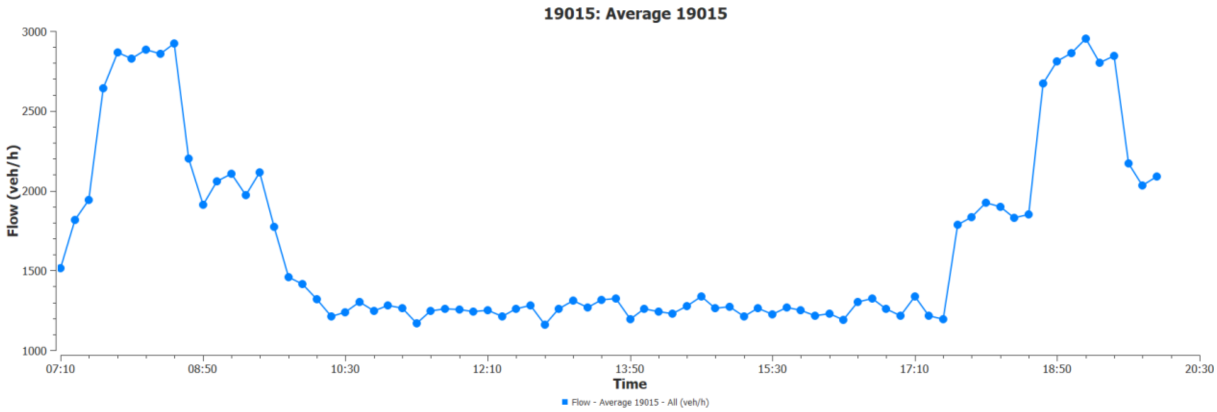


Figure 98. Flow average graph scenario 3A: Repl. 1 (18993), Repl. 2 (19012), Repl. 3 (19013), Repl. 4 (19014), Repl. 5 (19017)

Speaking of delay time, after the incrementation of the flow it was found some critical situations. In general, there was a hike of 151% concerning scenario 2 and 356% respect scenario 1, reaching values about 450 sec/km in some replications. These conditions are reflected in an oversaturation of the system, making it go into the collapse limit. This scene is the current situation that is experienced by hundreds of port cities. The maximum value reached in the average delay time graph was 209 sec/km being present in the peak afternoon hour, while in the morning, the maximum delay time was 178 sec/km.

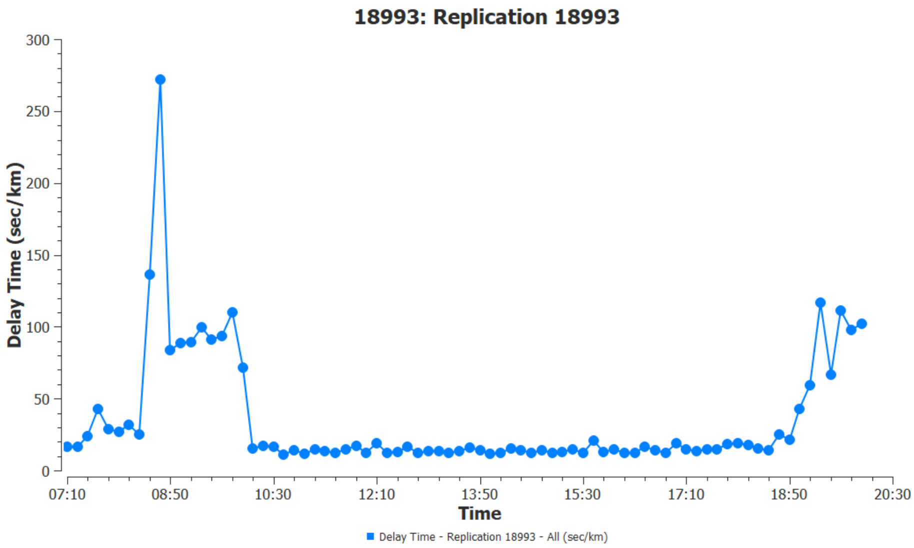


Figure 99. Delay time graph: Scenario 3A, replication 1

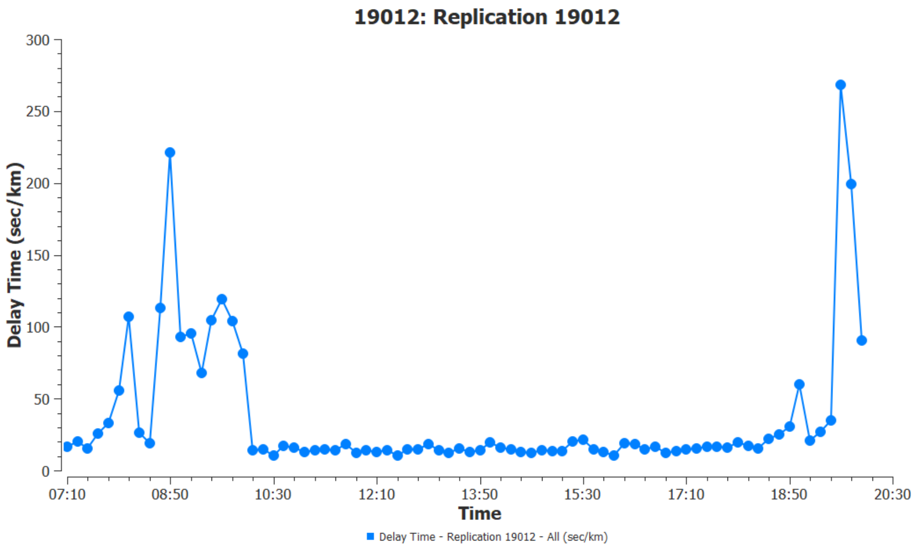


Figure 100. Delay time graph: Scenario 3A, replication 2

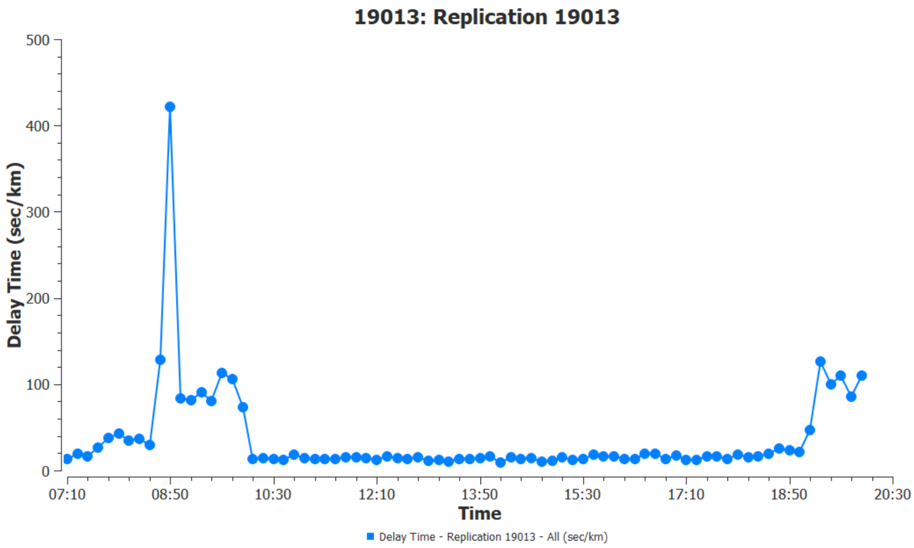


Figure 101. Delay time graph: Scenario 3A, replication 3

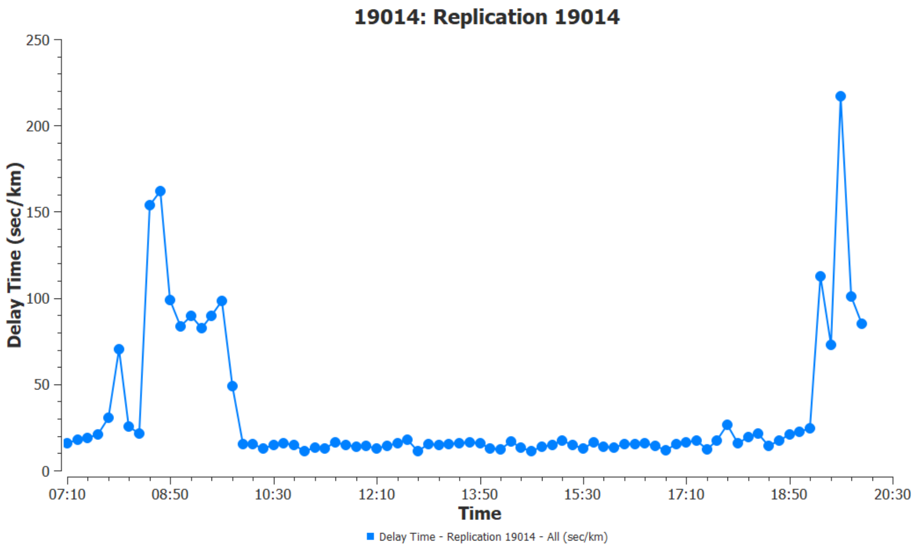


Figure 102. Delay time graph: Scenario 3A, replication 4

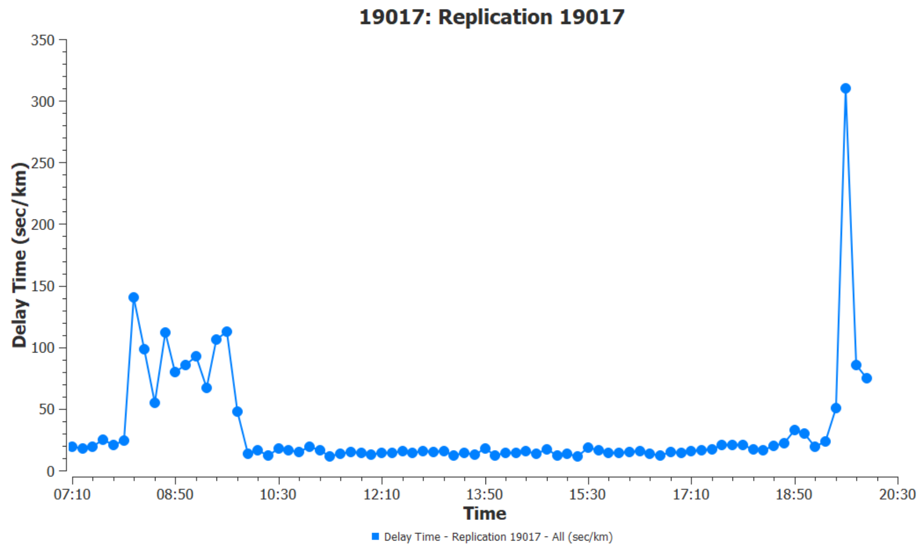


Figure 103. Delay time graph: Scenario 3A, replication 5

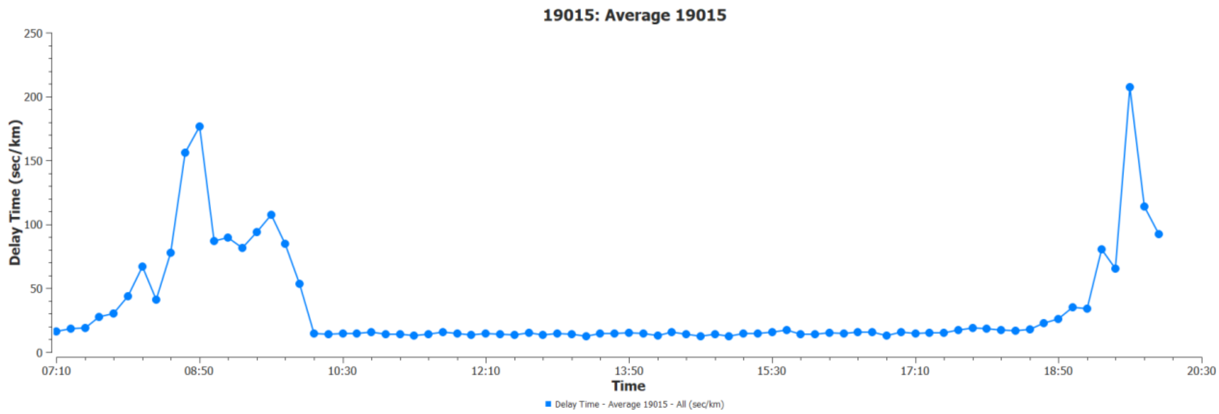


Figure 104. Delay time average graph scenario 3A: Repl. 1 (18993), Repl. 2 (19012), Repl. 3 (19013), Repl. 4 (19014), Repl. 5 (19017)

The results regarding the speed only reinforce the contention formulated before, it was observed in the different replication a critical drop of the velocity in the peak hours reaching values of almost 34 km/h that is translated into a poor level of service having in consideration that we are speaking about a system of the main motorway destined to evacuate the merchandise managed by the port. The overall system had a speed decrement of 10% but a 30% decrement in the peak hours period. The minimum value reached in the average graph was 36 km/h.

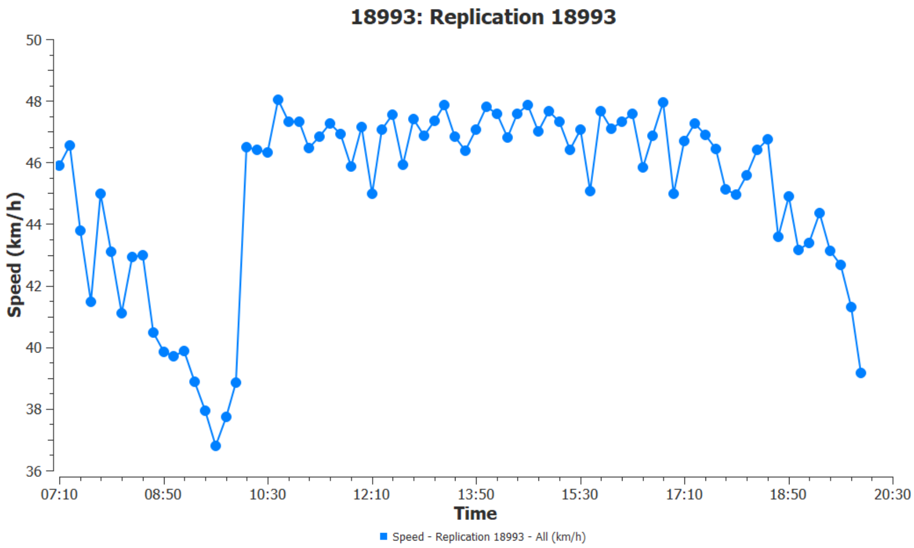


Figure 105. Speed graph: Scenario 3A, replication 1

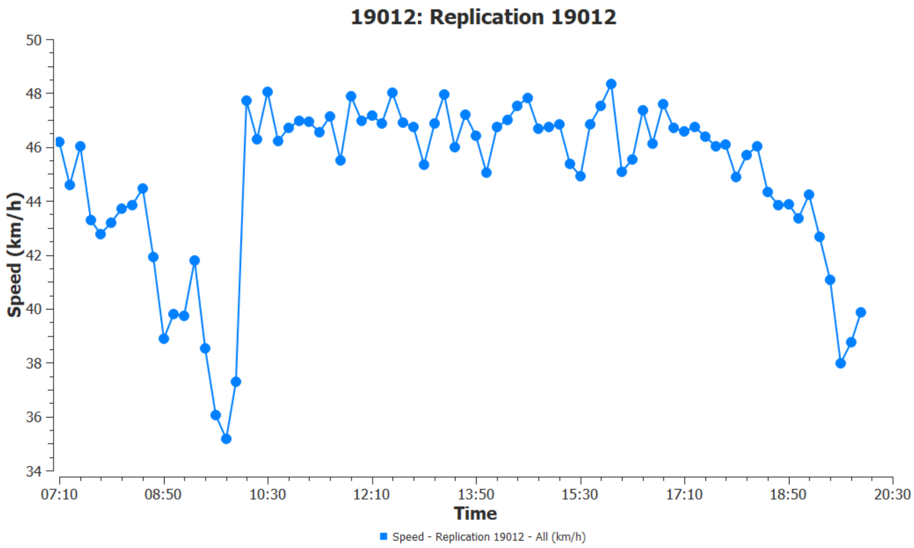


Figure 106. Speed graph: Scenario 3A, replication 2

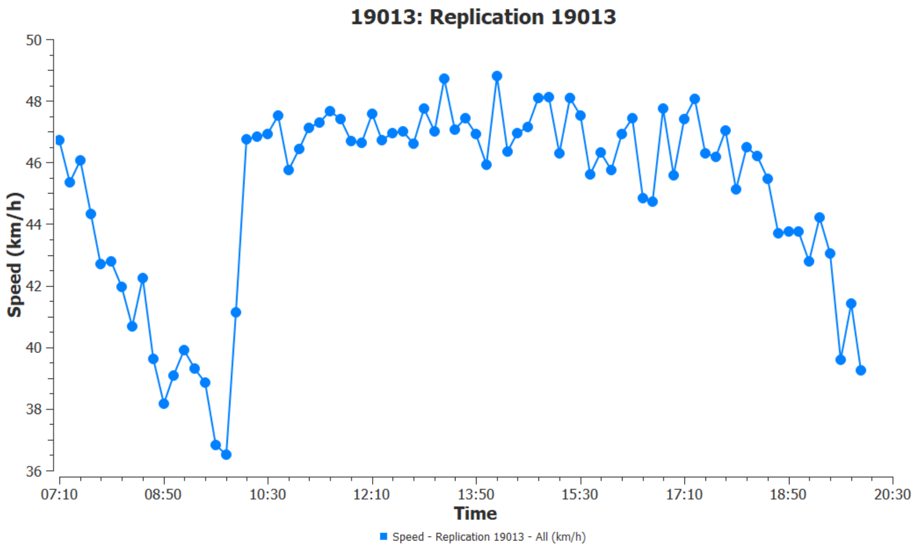


Figure 107. Speed graph: Scenario 3A, replication 3

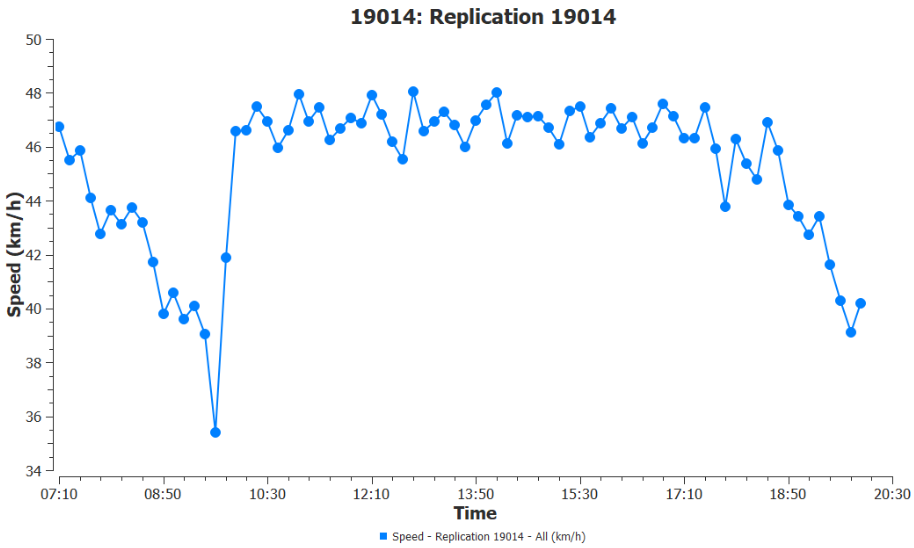


Figure 108. Speed graph: Scenario 3A, replication 4

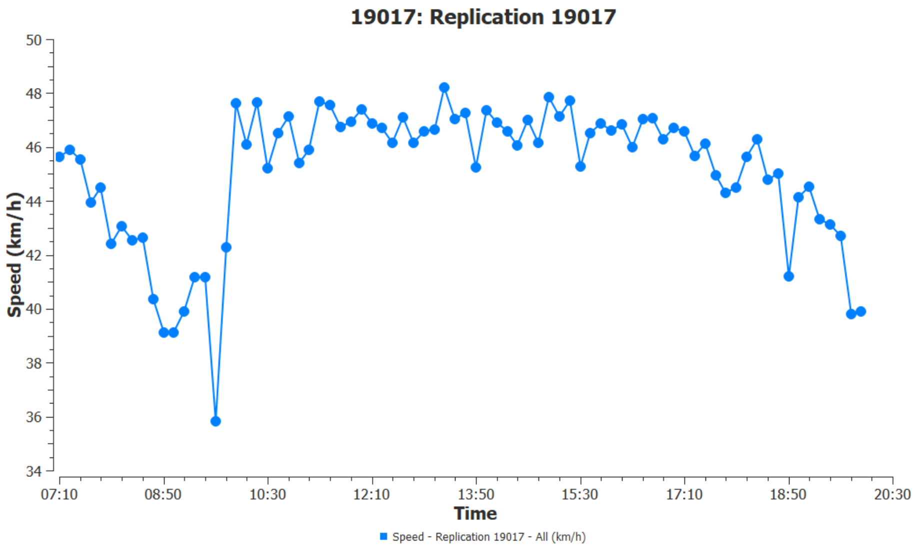


Figure 109. Speed graph: Scenario 3A, replication 5

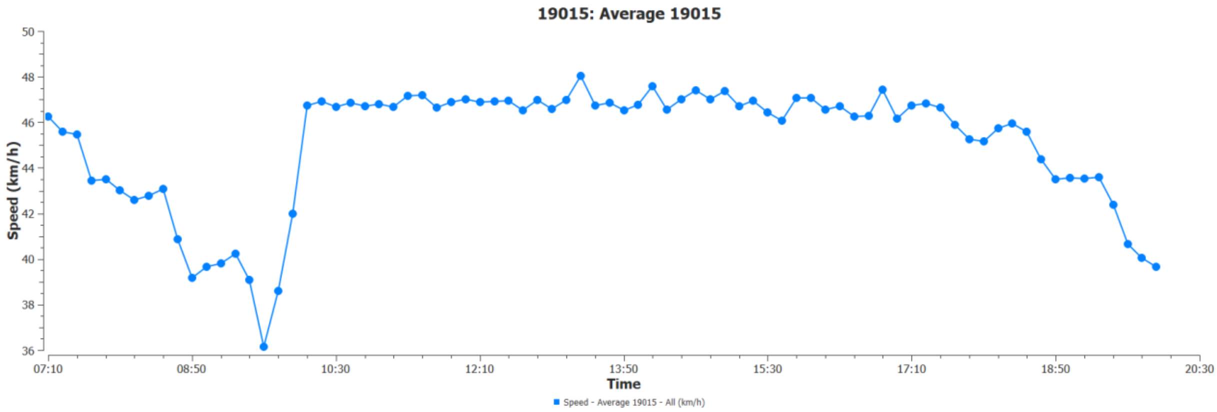


Figure 110. Speed average graph scenario 3A: Repl. 1 (18993), Repl. 2 (19012), Repl. 3 (19013), Repl. 4 (19014), Repl. 5 (19017)

In comparison with scenario 1 and 2, it was notorious the formation of very long queues and a worrying phenomenon of congestion. In Figure 111 and Figure 112 is shown the queue formations at the entrance of the port, that as shown in the chapter 2. 4) it has turn into a torture for the people of this cities, having long queues and critical waiting time but that also affect the throughput of the port and its competitive skills with the international market.

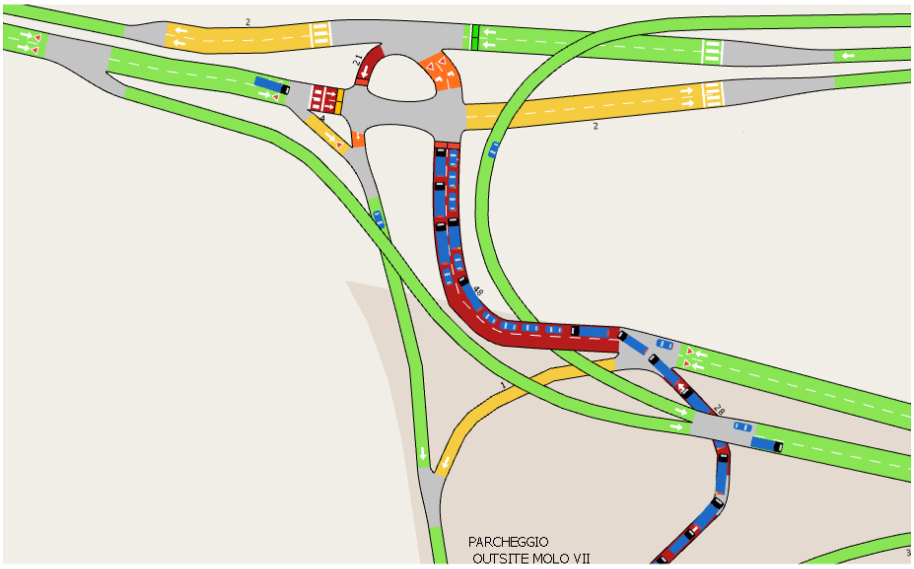


Figure 111. Software image of queue formation scenario 3 (1)

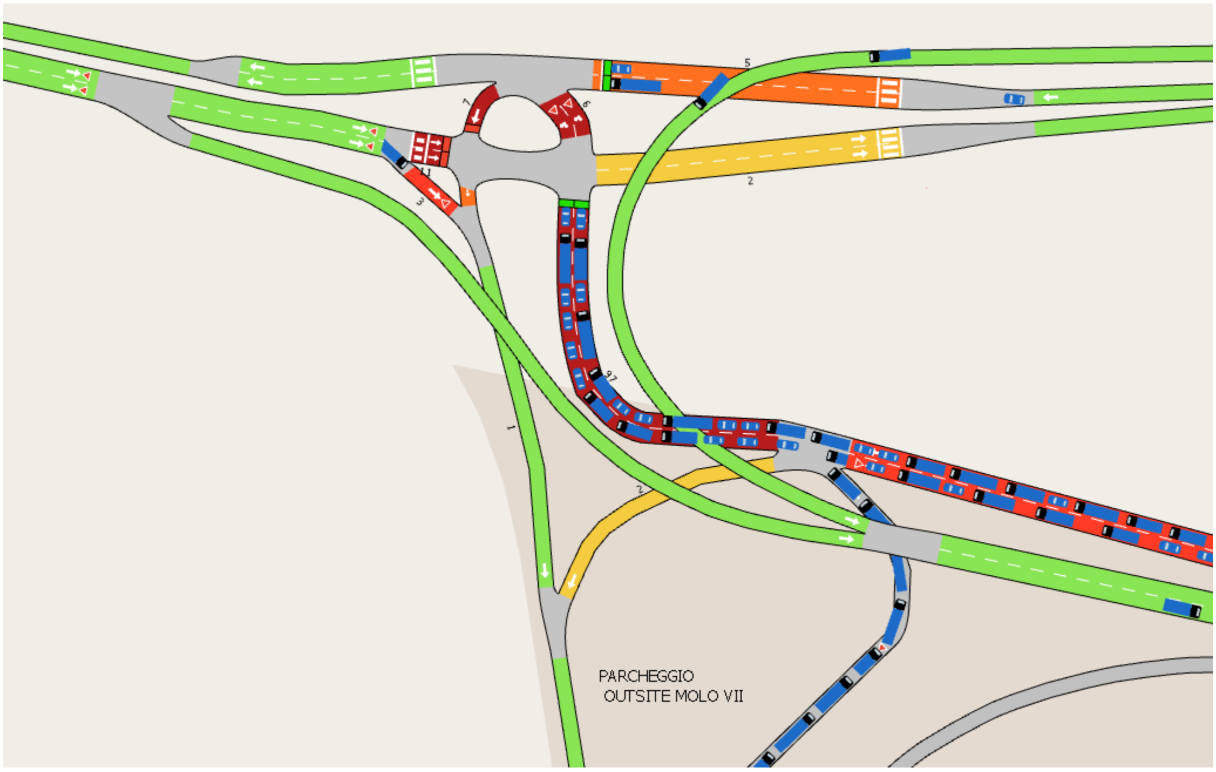


Figure 112. Software image of queue formation scenario 3 (2)

5.3.2. Scenario 3 B

As previously indicated, the semaphoric cycle was modified for this scenario variation, assigning a 60 second semaphoric cycle. The flow's behavior in some replications was equal to the previous scenario, but some events are important to highlight even though the average flow rate was pretty like scenario 3A. In replication 19501 (*Figure 114*), for the first time in the whole simulation, the system experiment a level of saturation that was not able to evacuate, taking the system into the collapse that why at the end of the graph, the flow rate is equal to 0, because the system was not running anymore as it can be seen in figure *Figure 119*. The maximum average value was 2743 veh/h that presents a reduction in respect to scenario 3A's maximum value (2907 veh/h).

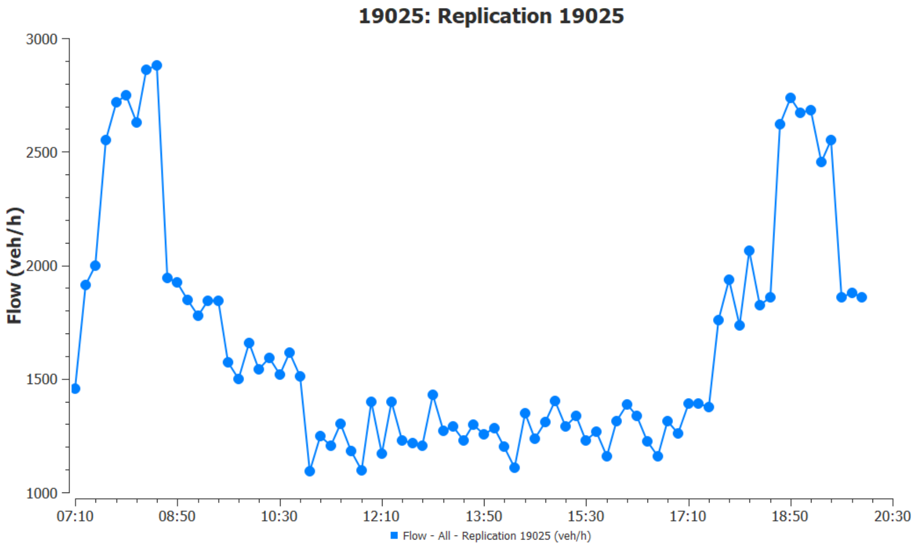


Figure 113. Flow graph: Scenario 3B, replication 1

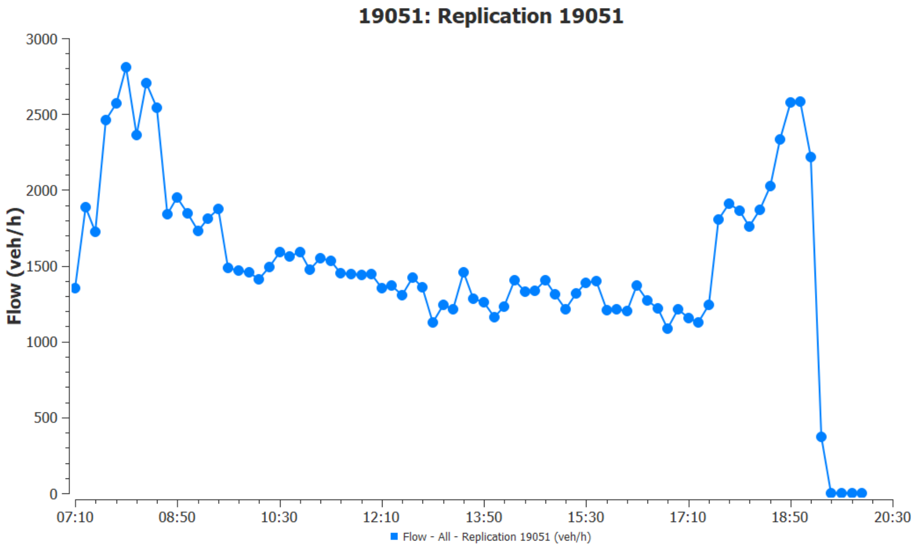


Figure 114. Flow graph: Scenario 3B, replication 2

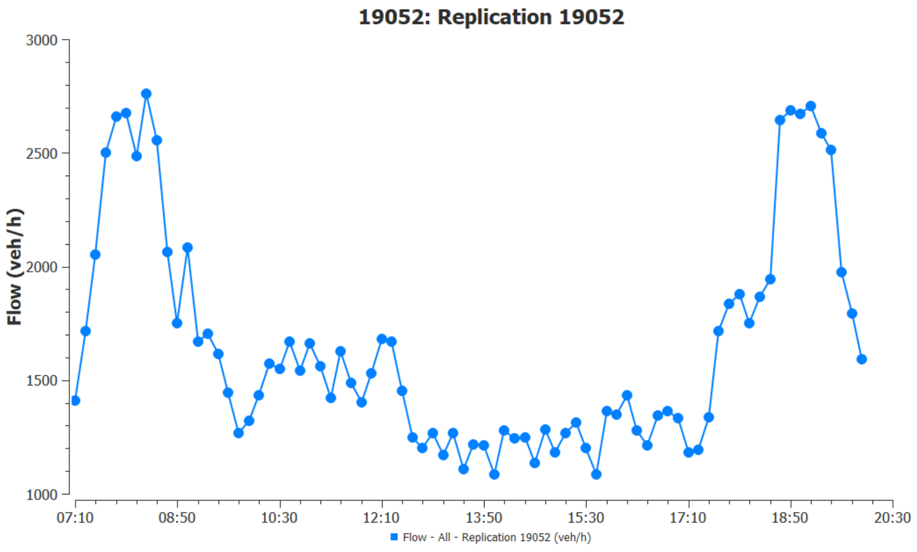


Figure 115. Flow graph: Scenario 3B, replication 3

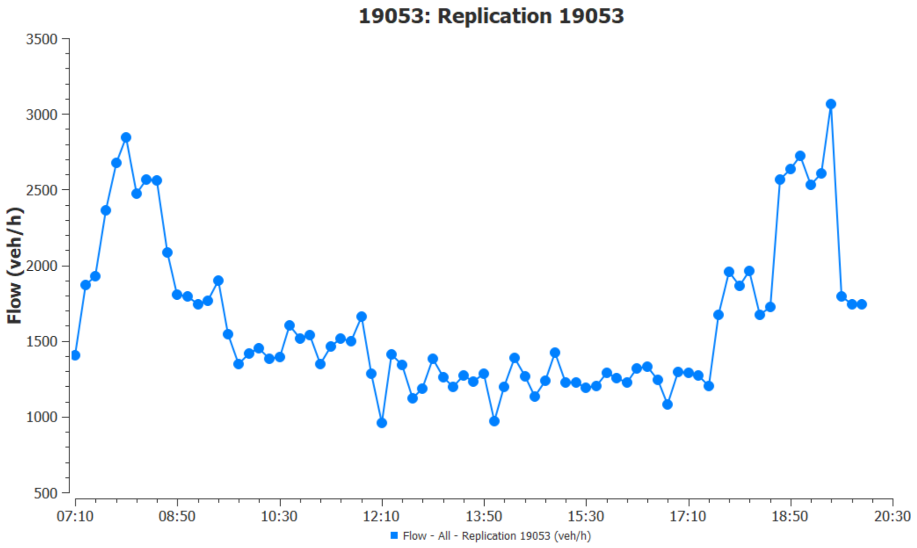


Figure 116. Flow graph: Scenario 3B, replication 4

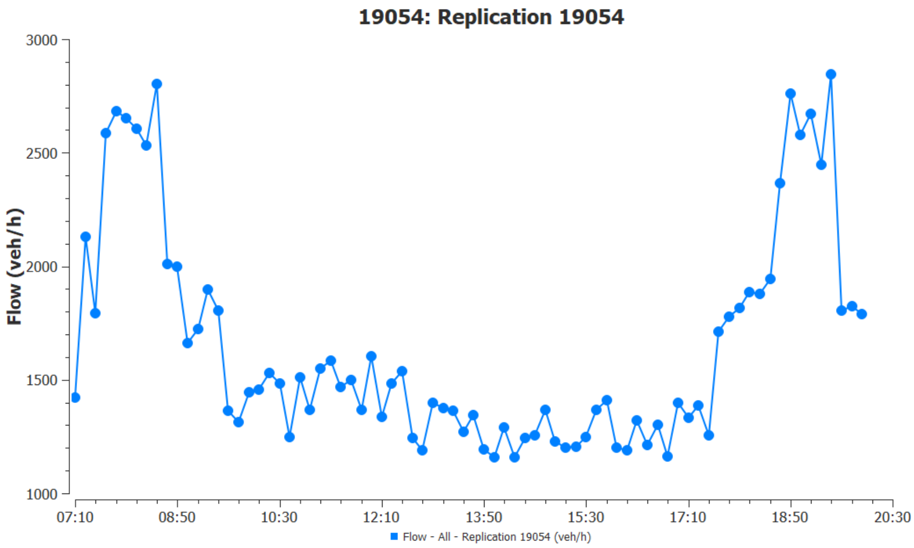


Figure 117. Flow graph: Scenario 3B, replication 5

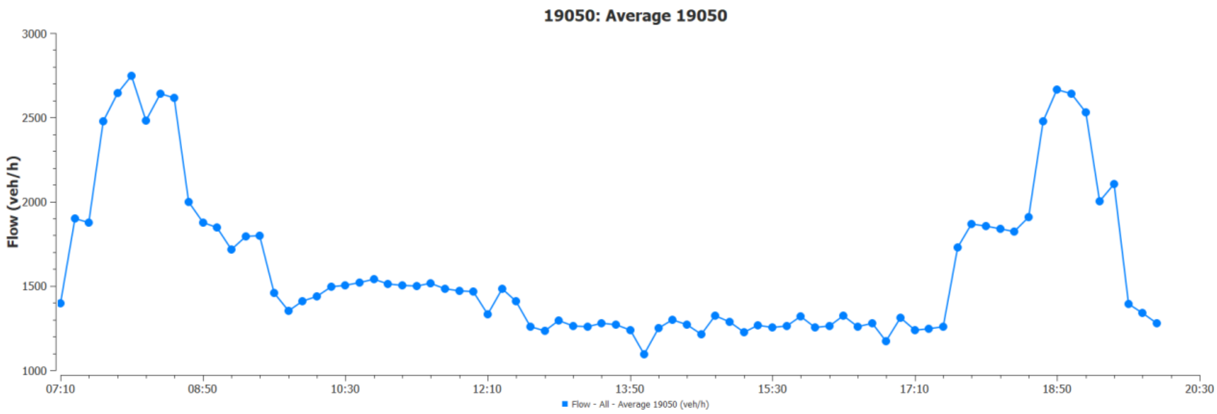


Figure 118. Flow average graph scenario 3B: Repl. 1 (19025), Repl. 2 (19051), Repl. 3 (19052), Repl. 4 (19053), Repl. 5 (19054)

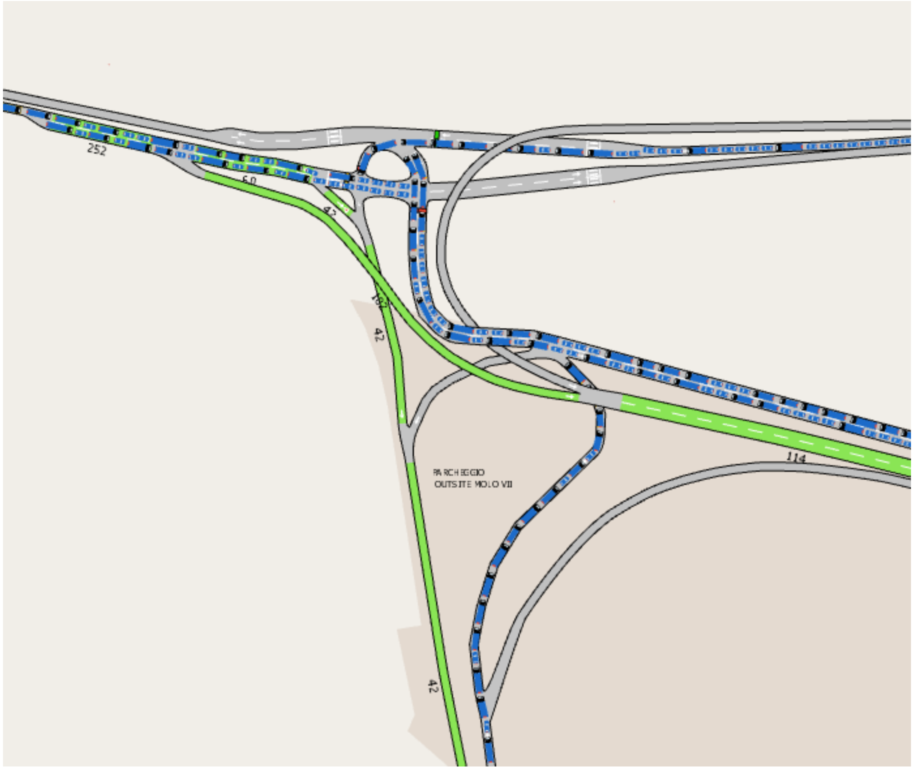


Figure 119. Block of the system with 60 s cycles

Concerning the delay time, some worrying and critical events can be observed. The average delay time was 81.74 sec/km representing an increment of two times the average delay time of scenario 3A (41.1 sec/km). The delay time graph of replication 19051 can be discarded, knowing that the model was not running due to the block that it was having. The system had a maximum delay time value of 852 sec/km, which is an alarming value compared to 209 sec/km of scenario 3A. Some replications reported maximum values of the order of 1500 sec/km.

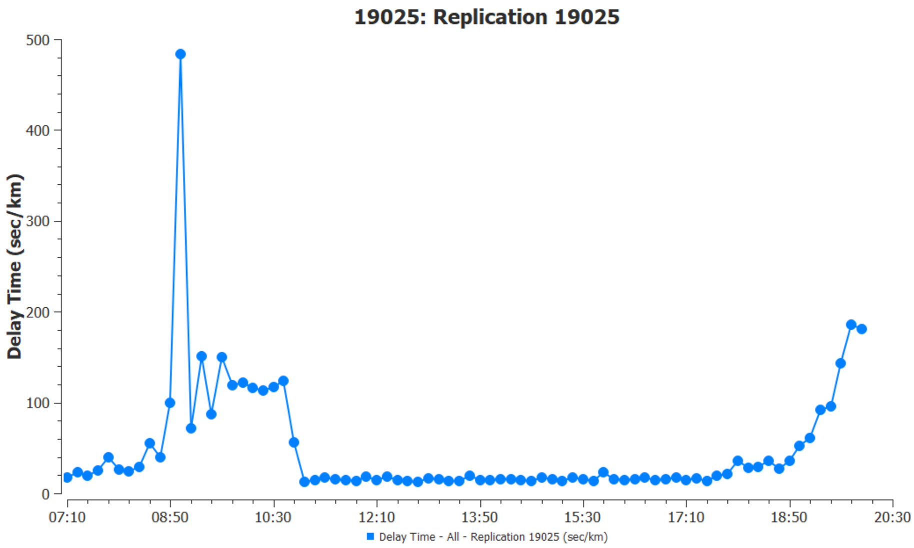


Figure 120. Delay time graph: Scenario 3B, replication 1

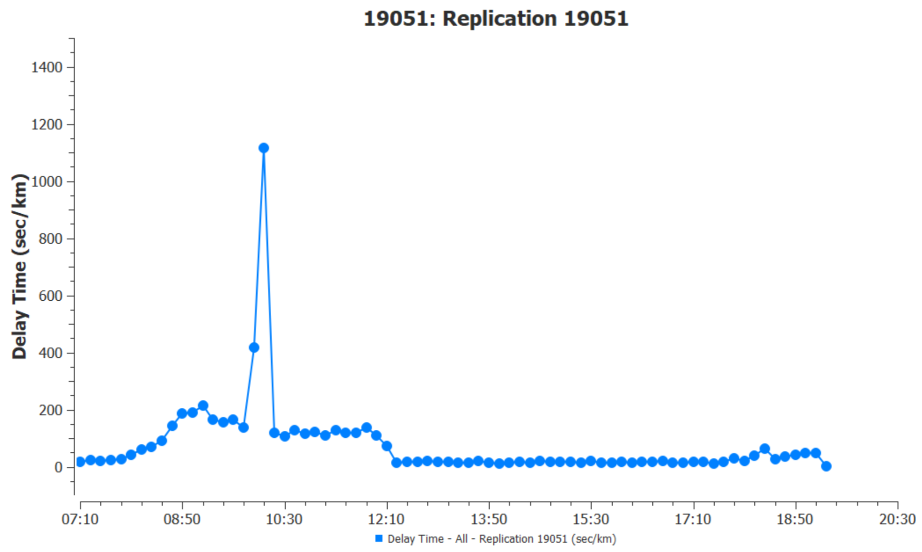


Figure 121. Delay time graph: Scenario 3B, replication 2

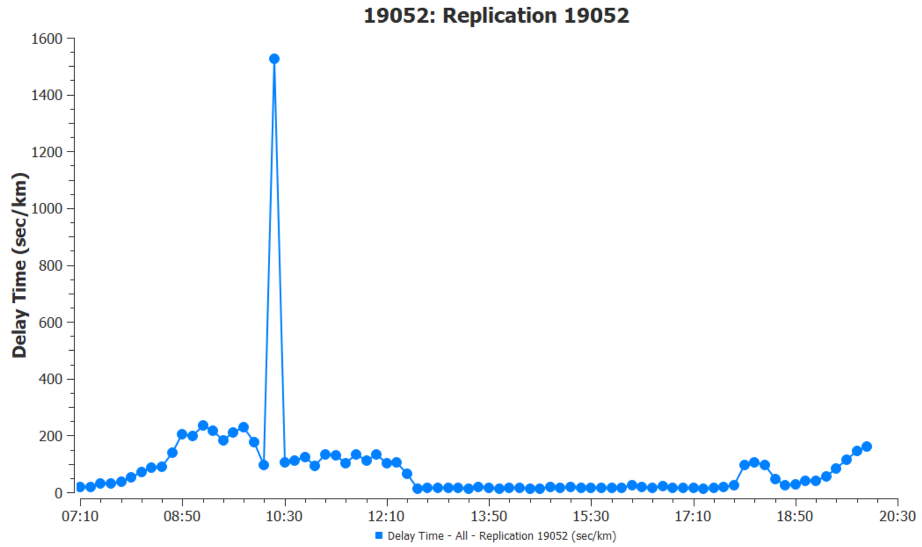


Figure 122. Delay time graph: Scenario 3B, replication 3

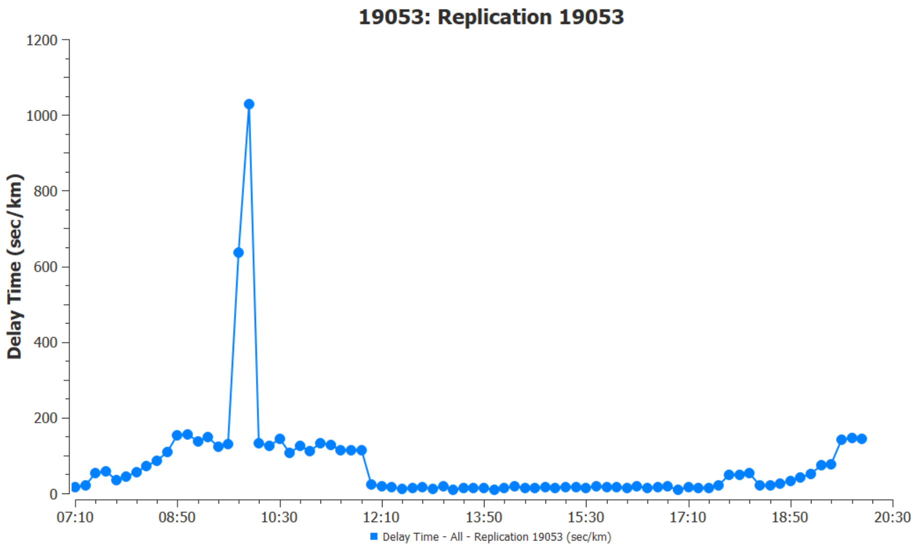


Figure 123. Delay time graph: Scenario 3B, replication 4

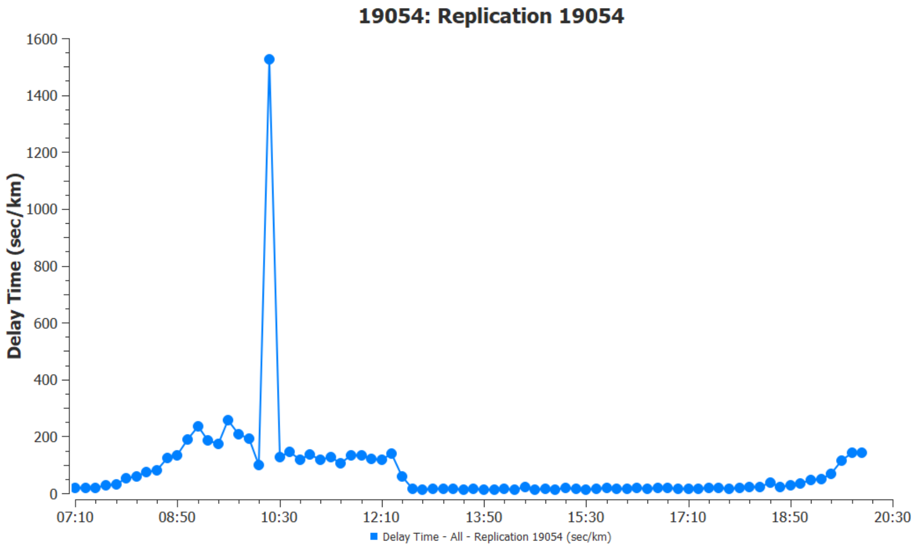


Figure 124. Delay time graph: Scenario 3B, replication 5

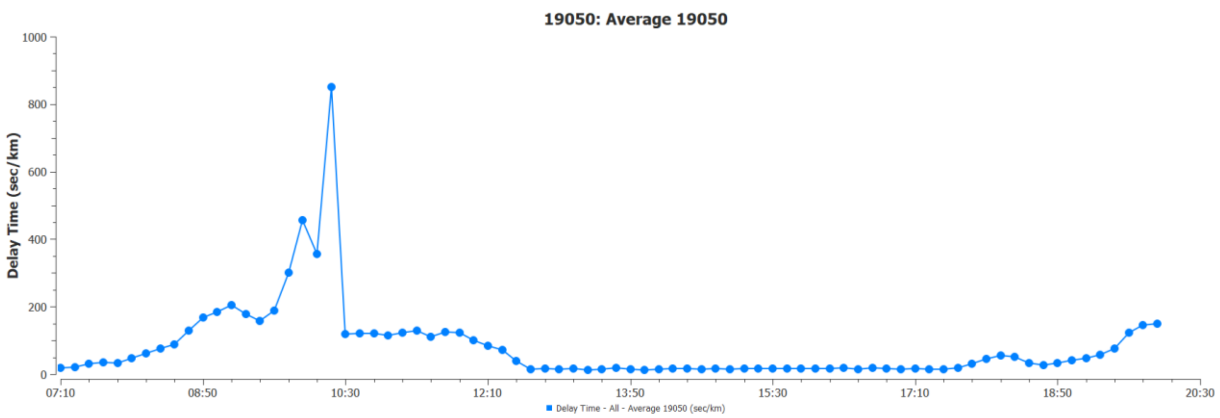


Figure 125. Delay time average graph scenario 3B: Repl. 1 (19025), Repl. 2 (19051), Repl. 3 (19052), Repl. 4 (19053), Repl. 5 (19054)

With respect to speed, the results represent the same situation expressed before. The throughput of the systems shows a decrement having values of less than 30 km/h in some replications, which is not acceptable for a motorway as SS202. The average speed value is 40.65 km/h that presents a decrement of 5 km/h for scenario 3A that was already showing alarming values. Still the replication 19051's graph for speed is not taking into account given the not representation of the network caused by the block when it was launched.

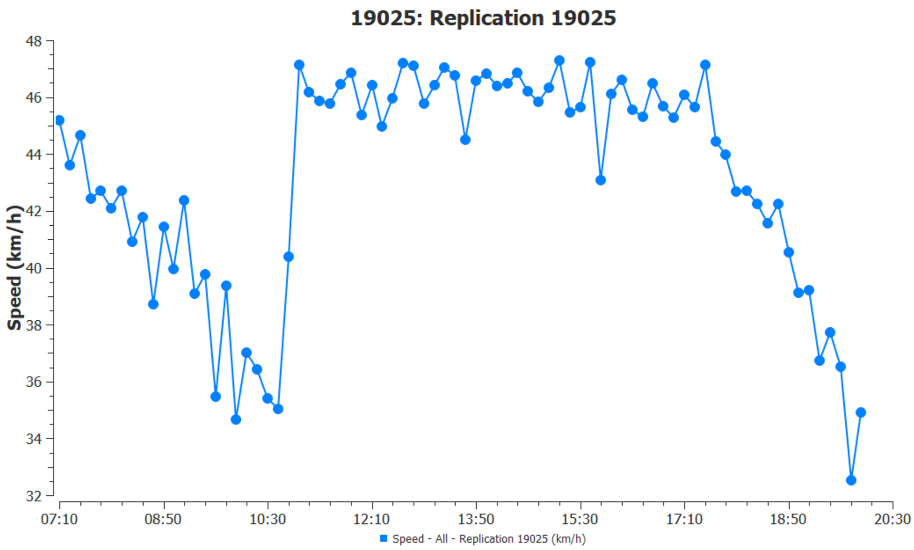


Figure 126. Speed graph: Scenario 3B, replication 1

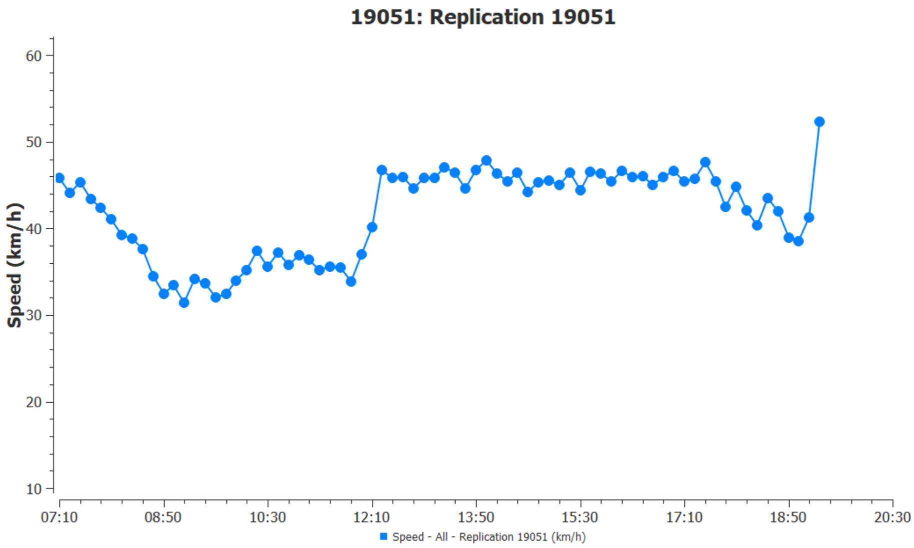


Figure 127. Speed graph: Scenario 3B, replication 2

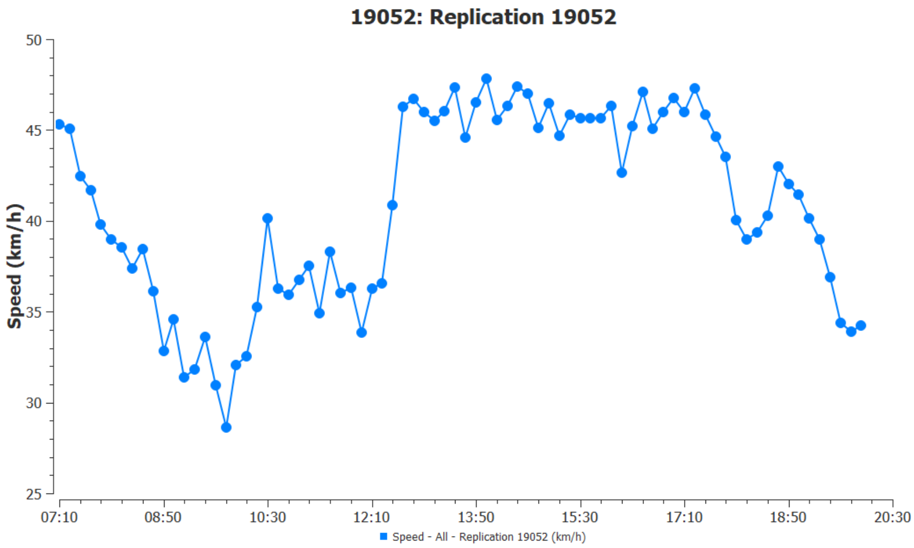


Figure 128. Speed graph: Scenario 3B, replication 3

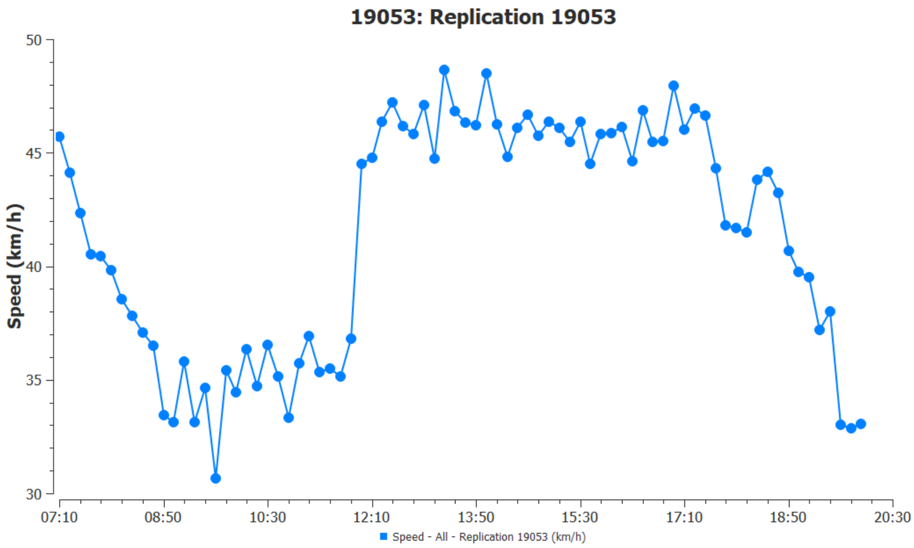


Figure 129. Speed graph: Scenario 3B, replication 4

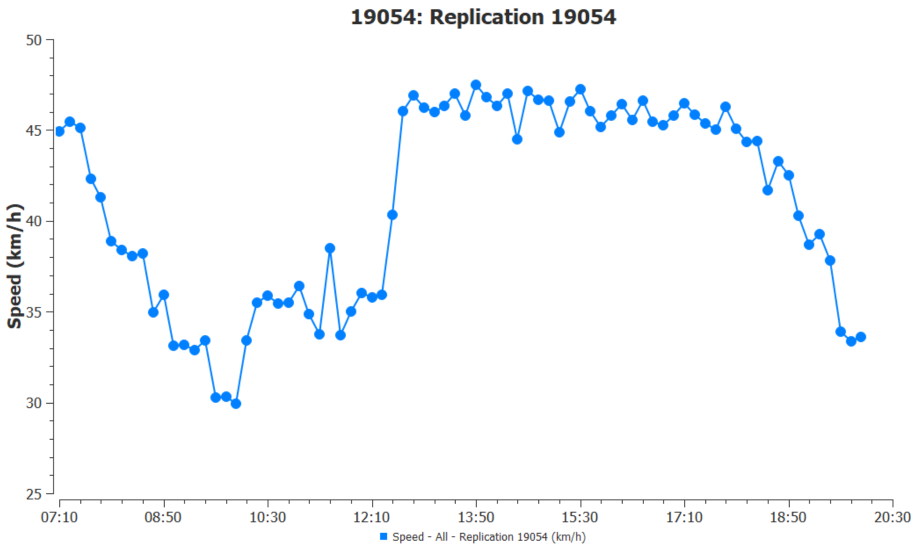


Figure 130. Speed graph: Scenario 3B, replication 5

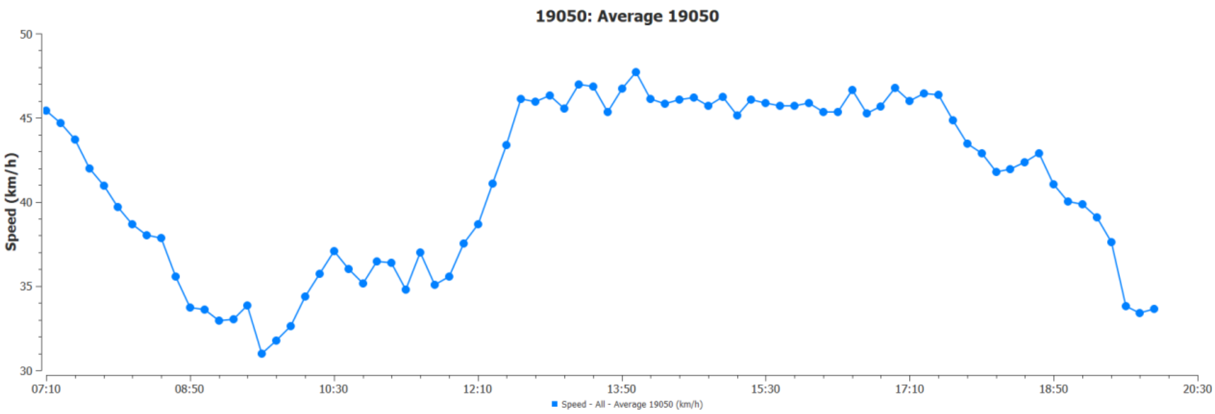


Figure 131. Speed average graph scenario 3B: Repl. 1 (19025), Repl. 2 (19051), Repl. 3 (19052), Repl. 4 (19053), Repl. 5 (19054)

In general, it was seen that 60-second cycles represent a decrement for the whole system performance and show how important is the control plan configuration in a network. Not having the exact times of the intersections, the presence of this scenario arrangement in SS2202's intersection with Viale Campi Elisi is still possible and an optimization in the semaphoric cycle time should be done first of the implementation of the proposed ITS system.

5.3.3. Scenario 3 C

As previously indicated, the semaphoric cycle was modified for this scenario variation, assigning a 120-second semaphoric cycle. The average flow rate reported for this scenario is 1593 veh/h that does not represent a meaningful change concerning scenario 3A. Nevertheless, it presented a higher maximum average value (3064 veh/h) with respect to scenario 3A (2923 veh/h), translated into a higher system's higher capacity in peak hours. It is also important to spotlight that replication 5 (19049) suffered a block in the network as happened in scenario 3B;

it can be said that it was expected due to the central axis of this thesis that sustain that naval gigantism is collapsing inland networks by the vast quantity of traffic that it generates.

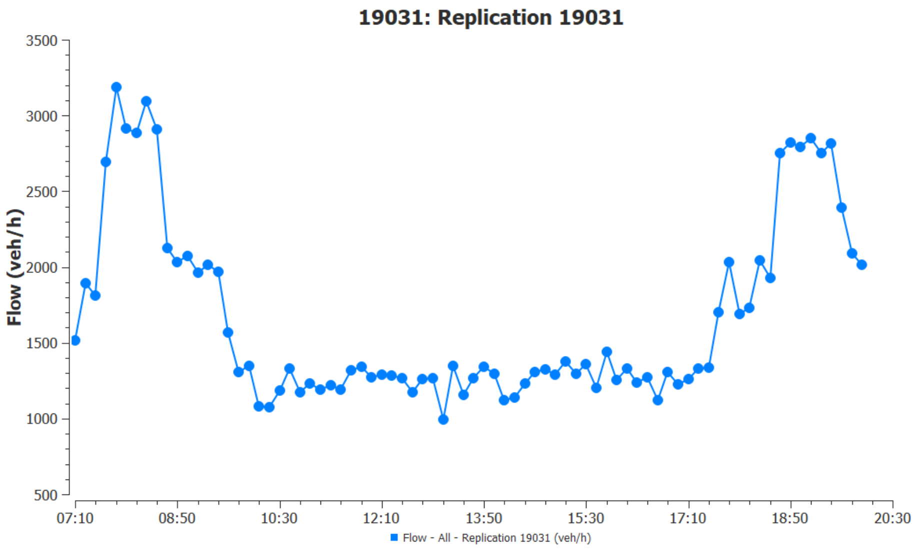


Figure 132. Flow graph: Scenario 3C, replication 1

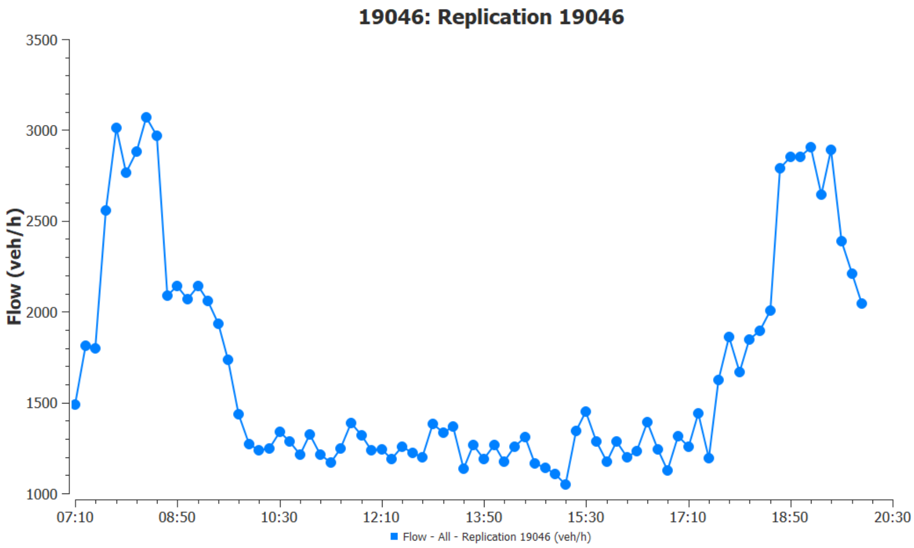


Figure 133. Flow graph: Scenario 3C, replication 2

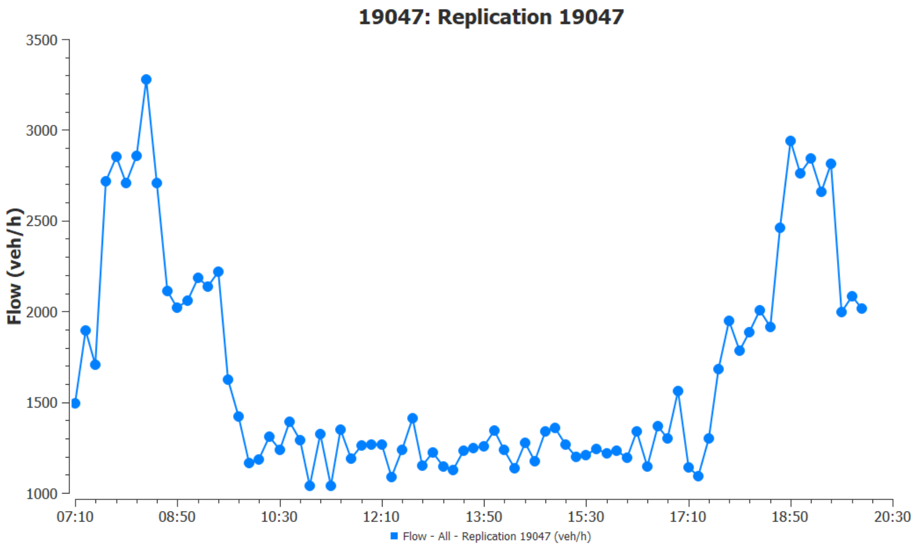


Figure 134. Flow graph: Scenario 3C, replication 3

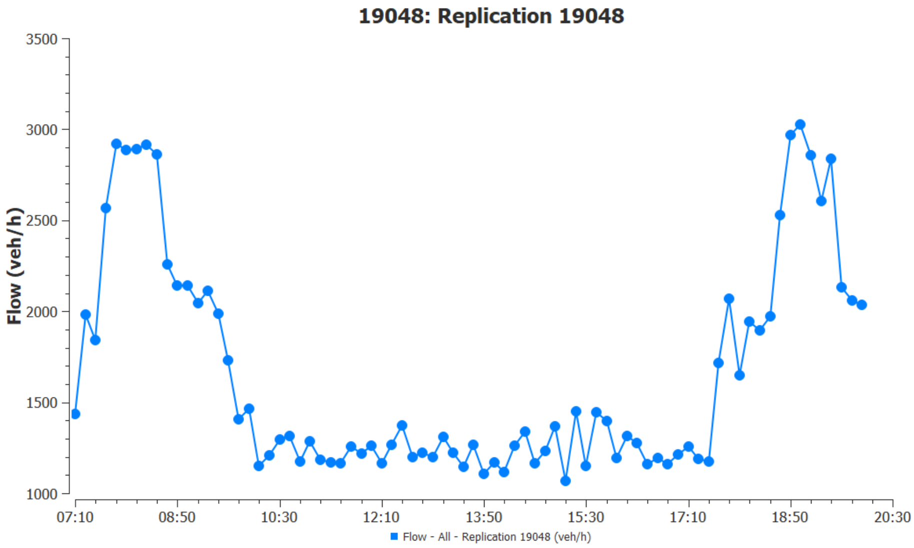


Figure 135. Flow graph: Scenario 3C, replication 4

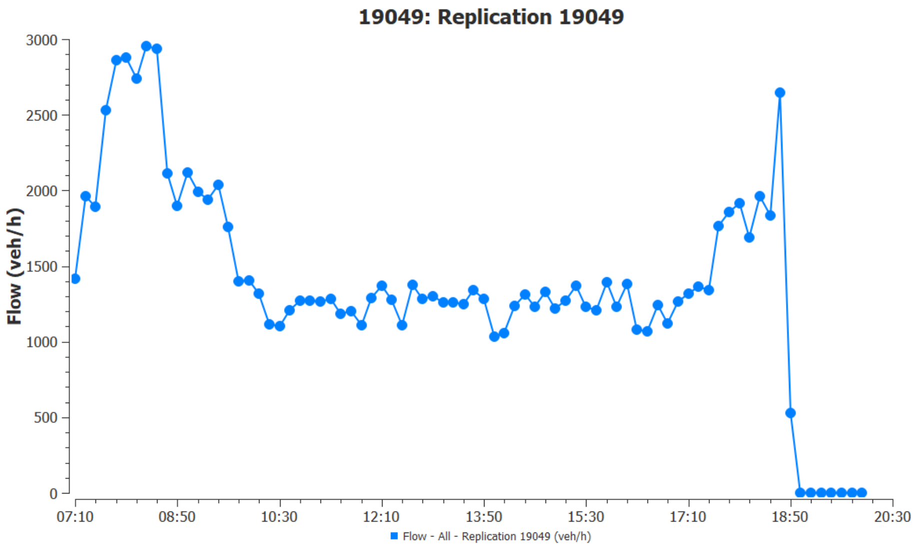


Figure 136. Flow graph: Scenario 3C, replication 5

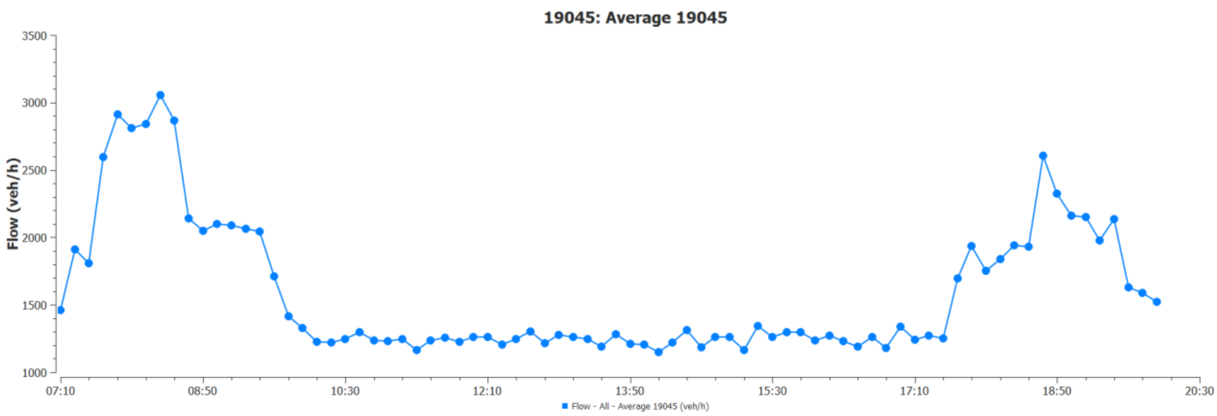


Figure 137. Flow average graph scenario 3C: Repl. 1 (19031), Repl. 2 (19046), Repl. 3 (19047), Repl. 4 (19048), Repl. 5 (19049)

The delay time graph's behavior presents a better situation than scenario 3B, reducing 50 % in the average delay time; 41.7 sec/km with respect of 81.74 sec/km present in scenario 3B. Comparing with scenario 3A, the situation did not vary that much, remembering that scenario 3A has 41.1 sec/km as an average value. Also, the maximum values have the same order of scenario 3A, 210 sec/km compared to 207 sec/km. The graph of replication 5 (19049) is not taken into account because it is not representative.

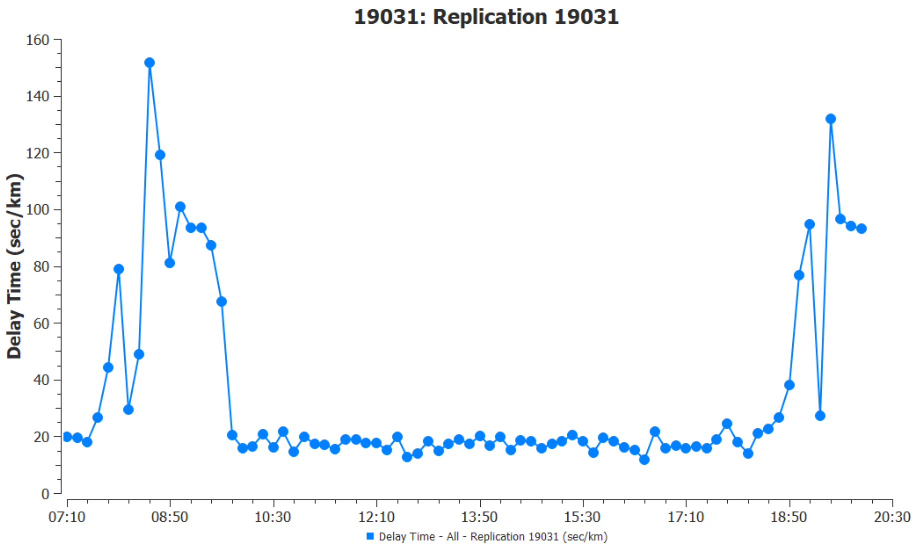


Figure 138. Delay time graph: Scenario 3C, replication 1

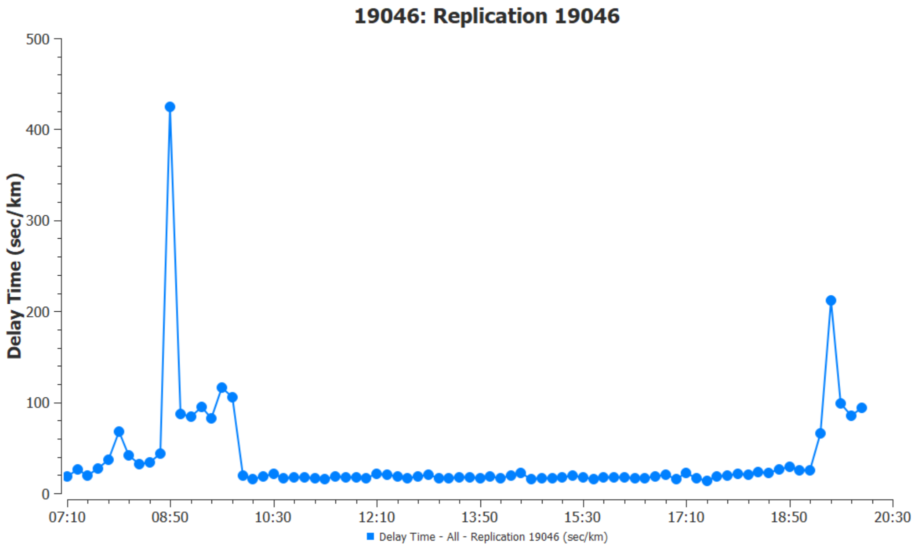


Figure 139. Delay time graph: Scenario 3C, replication 2

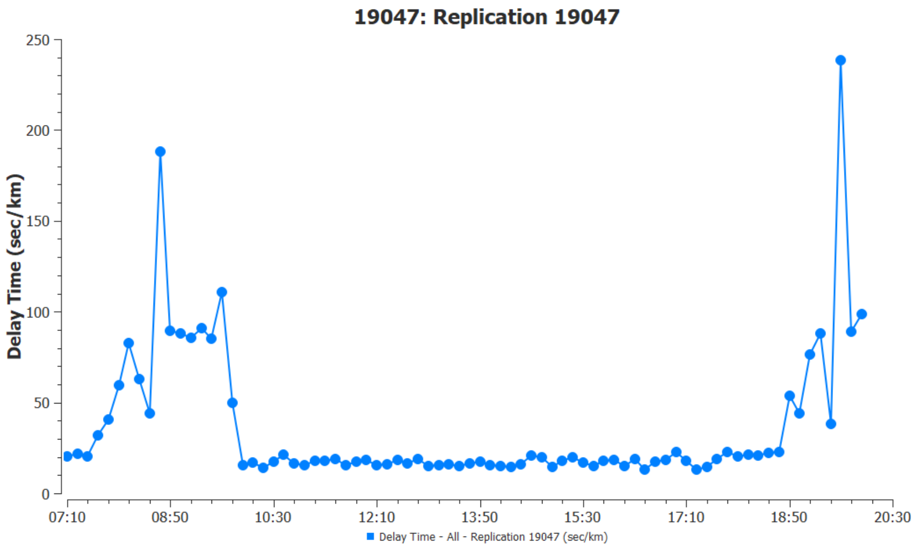


Figure 140. Delay time graph: Scenario 3C, replication 3

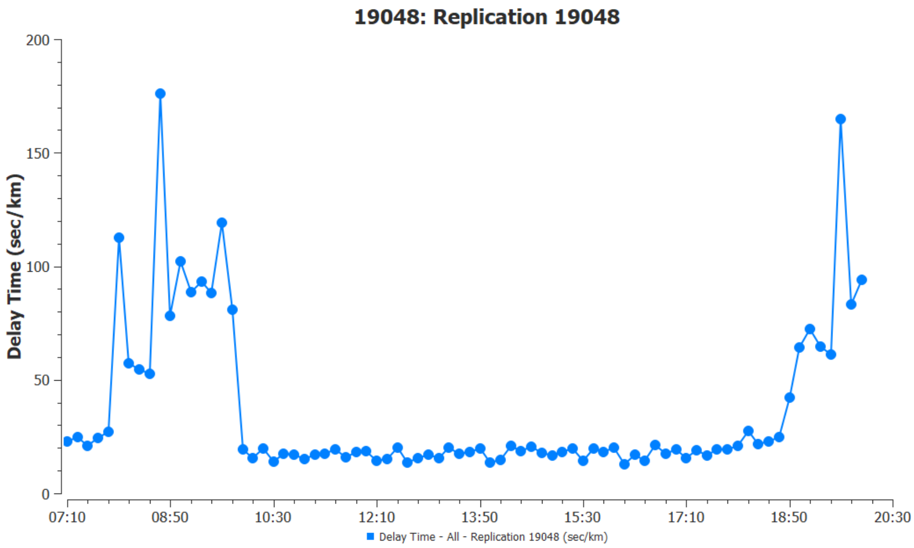


Figure 141. Delay time graph: Scenario 3C, replication 4

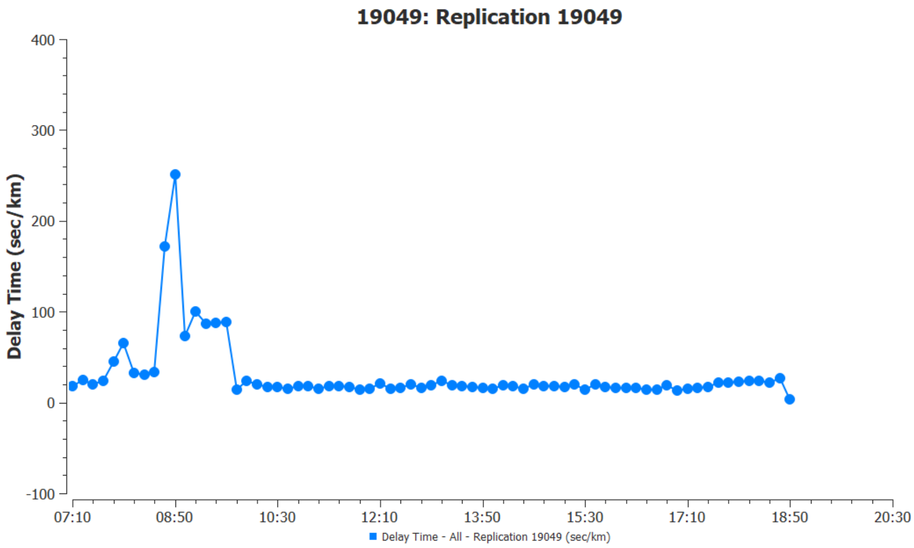


Figure 142. Delay time graph: Scenario 3C, replication 5

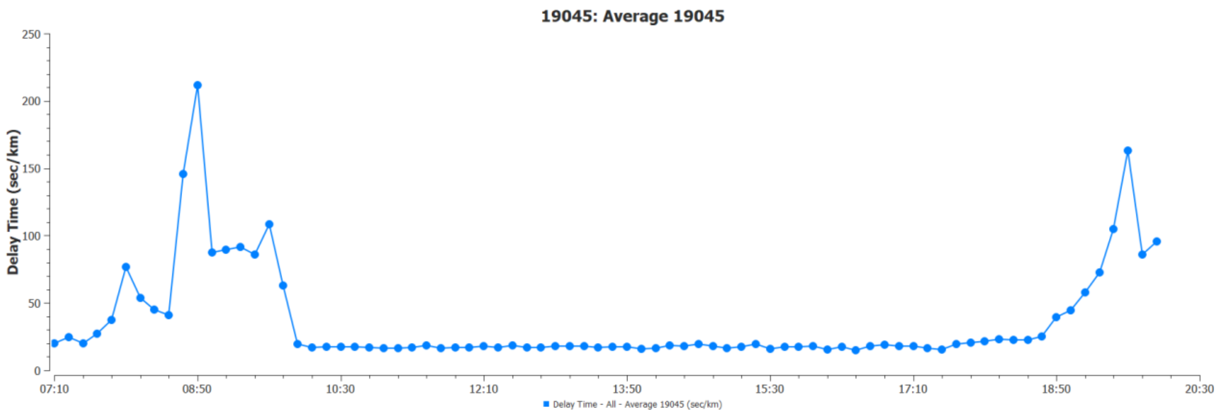


Figure 143. Delay time average graph scenario 3C: Repl. 1 (19031), Repl. 2 (19046), Repl. 3 (19047), Repl. 4 (19048), Repl. 5 (19049)

Concerning speed, the results do not present immense variation with respect to scenario 3A. The average speed is 43.54 km/h compared to 44.47 km/h of scenario 3A. Some replications reached minimum values of about 33 km/h, and the minimum average value is 36.4km/h that, again, does not vary in comparison with 36.1 km/h of scenario 3A, which means that even with a broader cycle, the traffic situation continues being worrying. The replication 19051's graph for speed is not considered given the not representation of the network caused by the block when it was launched.

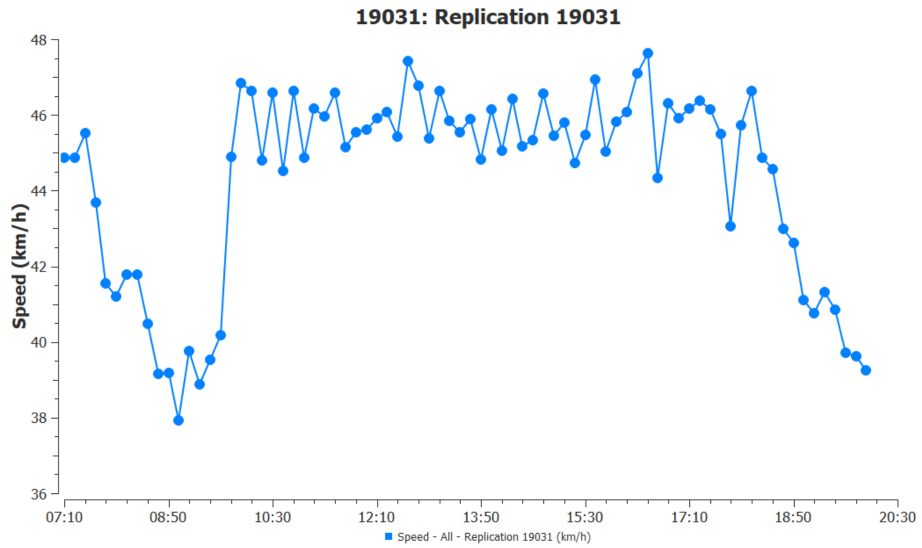


Figure 144. Speed graph: Scenario 3C, replication 1

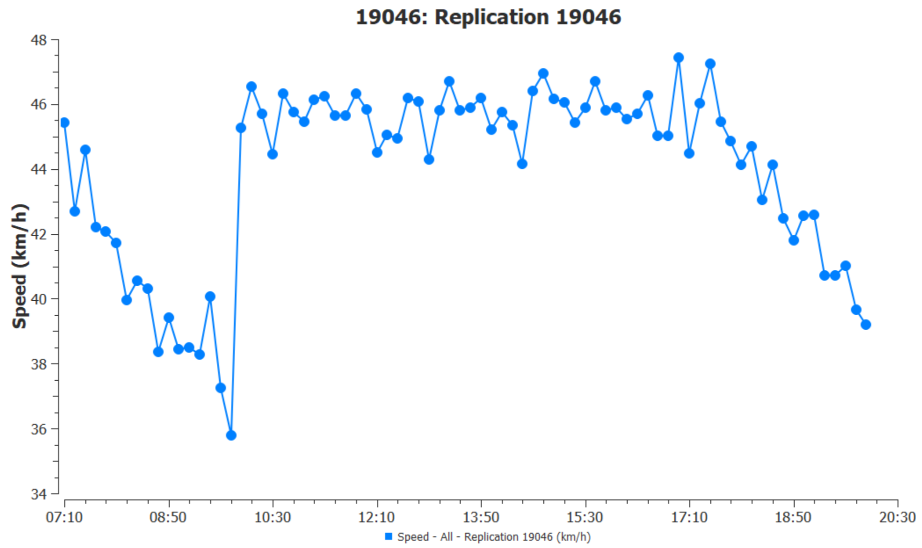


Figure 145. Speed graph: Scenario 3C, replication 2

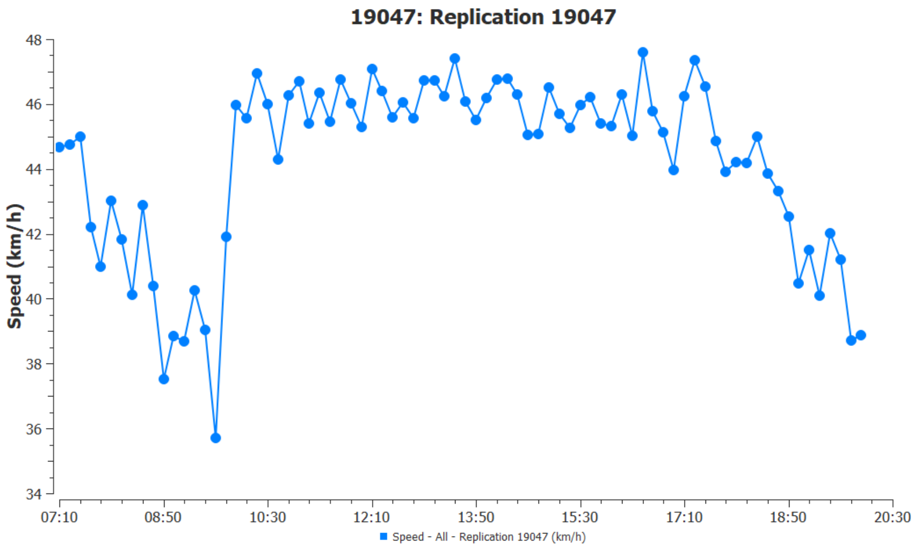


Figure 146. Speed graph: Scenario 3C, replication 3

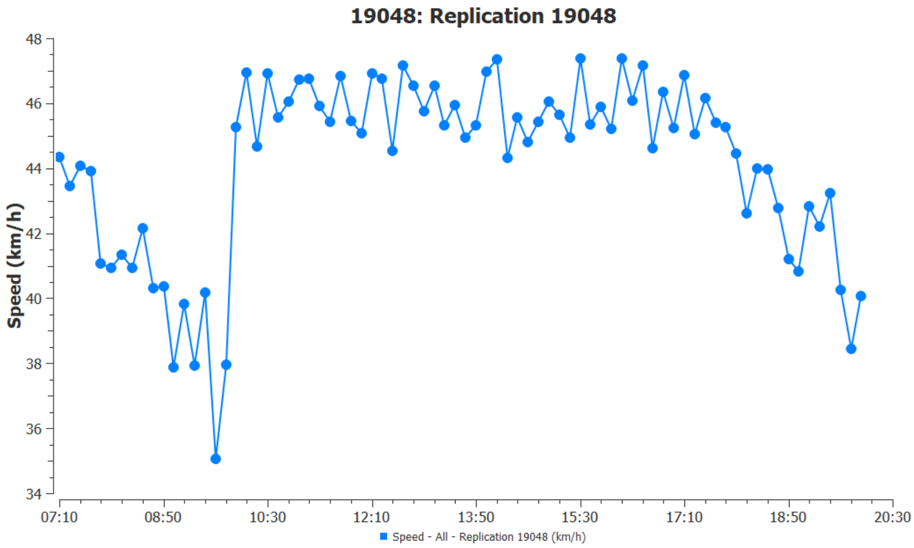


Figure 147. Speed graph: Scenario 3C, replication 4

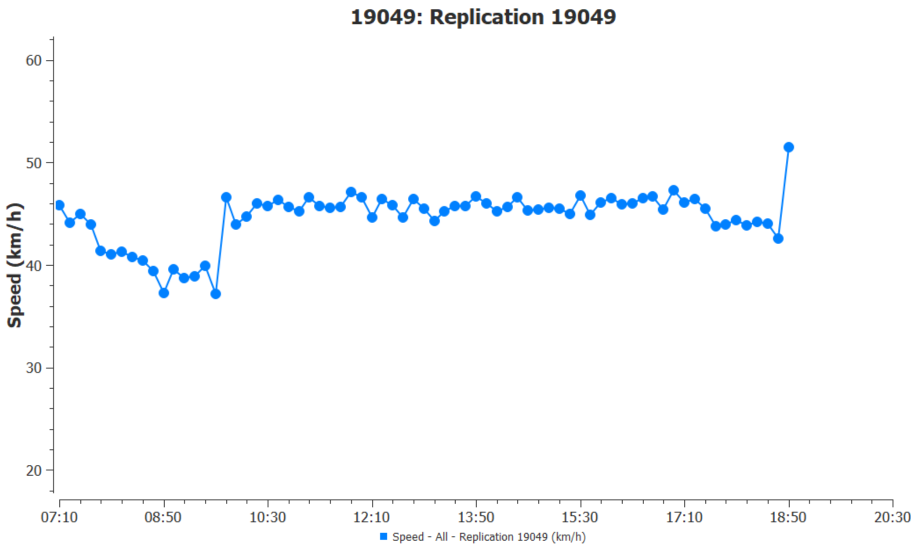


Figure 148. Speed graph: Scenario 3C, replication 5

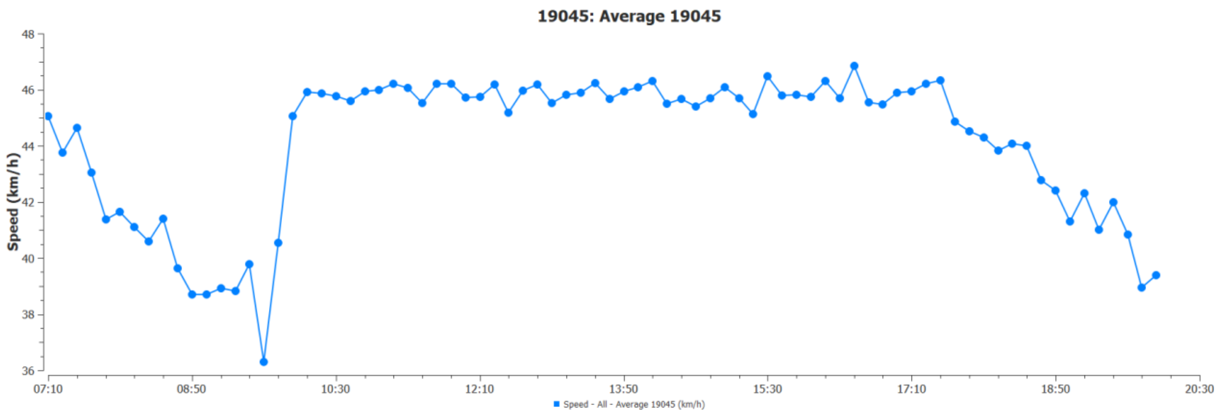


Figure 149. Speed average graph scenario 3C: Repl. 1 (19031), Repl. 2 (19046), Repl. 3 (19047), Repl. 4 (19048), Repl. 5 (19049)

In general, the increment of the cycle did not affect significantly as the reduction did, but it is still important to remember that to determine with more accuracy the effects of an ITS system in a network, it is essential to have a complete characterization of this one. In this case, given the non-availability of the data, the last scenario was carried out with Scenario 3A, considering the most representative being the average of the two edge scenarios.

5.4. Scenario 4 – ITS solution for Naval Gigantism situation

For this scenario, which is the result of scenario 3A's redistribution following the semaphoric cycle configuration of scenario 3A, it was essential to verify the compliance with this one. The first step was to verify that the input flow of both scenarios was the exact intending to certify that the same quantity of vehicles was being simulated. For scenario 3, the input count was 21779.6 vehicles, while for scenario 4 was 21827.2 vehicles. As it can be observed, the flow magnitude is almost the same. It is noticed that in the different replications, the tendency was to render the more constant the graphic, and even though the number of cars was the same, the maximum flow reached by the average graph was 1997 veh/h having a reduction of 31% in comparison with scenario 3A.

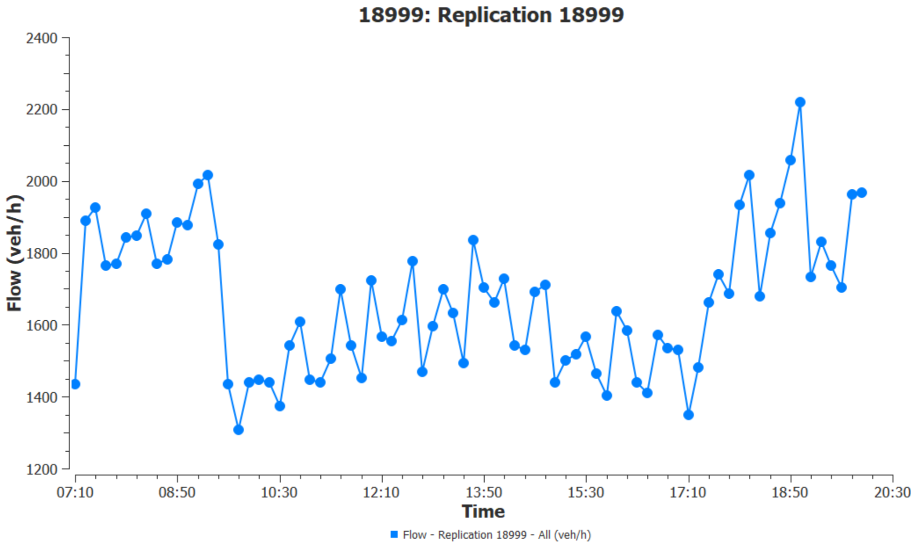


Figure 150. Flow graph: Scenario 4, replication 1

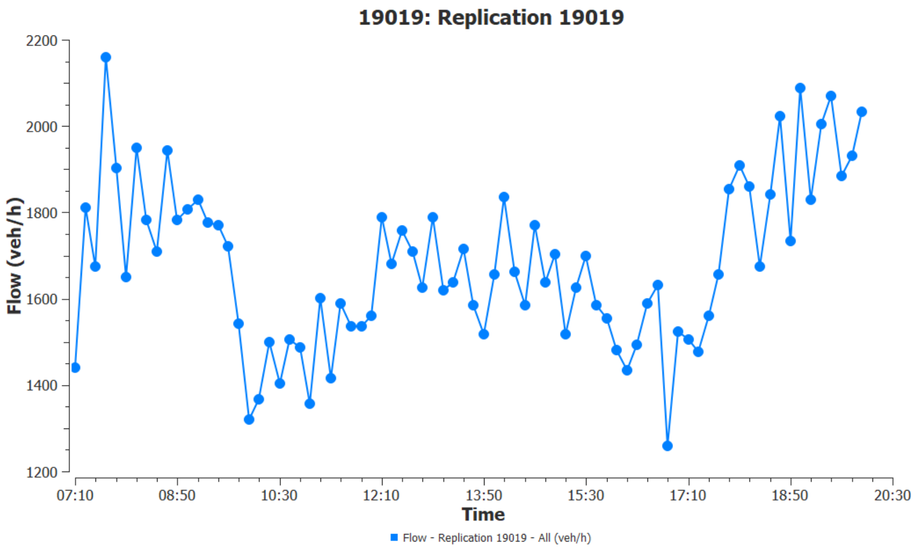


Figure 151. Flow graph: Scenario 4, replication 2

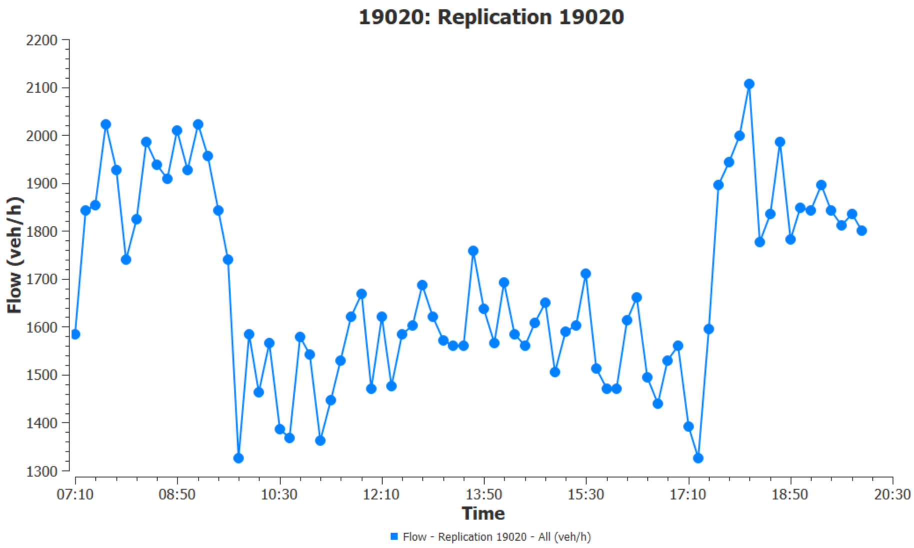


Figure 152. Flow graph: Scenario 4, replication 3

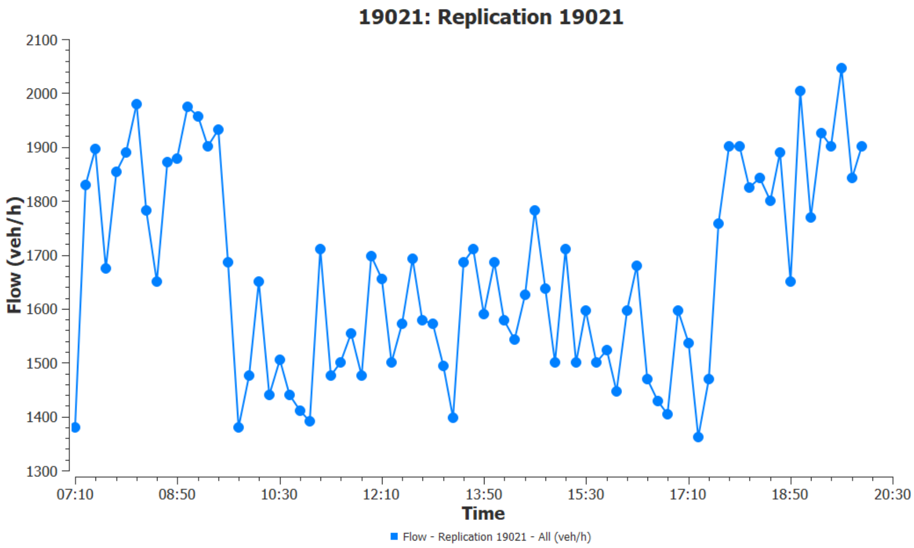


Figure 153. Flow graph: Scenario 4, replication 4

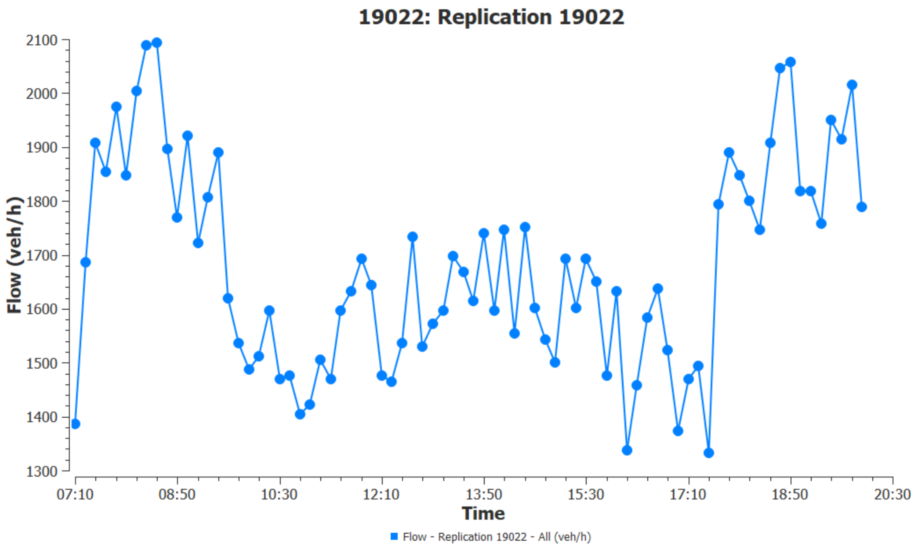


Figure 154. Flow graph: Scenario 4, replication 5

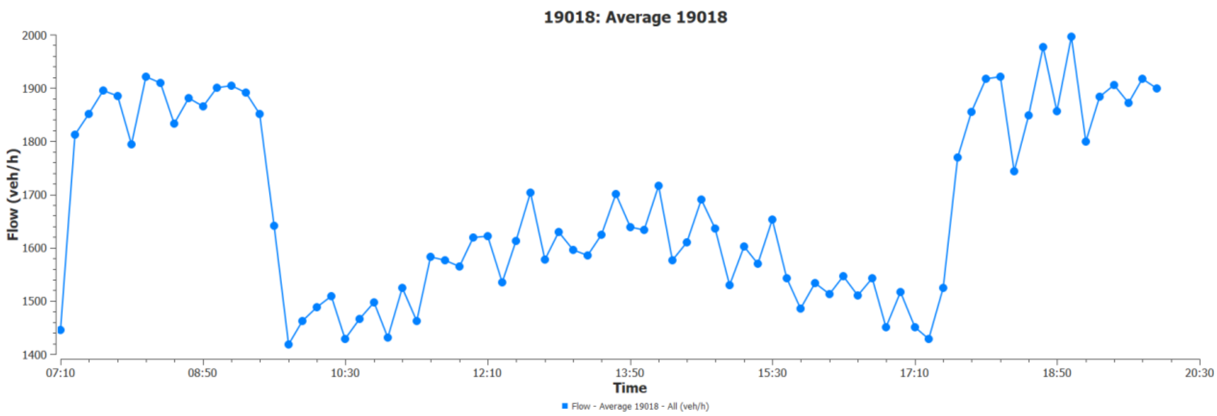


Figure 155. Flow average graph scenario 4: Repl. 1 (18999), Repl. 2 (19019), Repl. 3 (19020), Repl. 4 (19021), Repl. 5 (19022)

Speaking of delay time, the improvement was evident. The system did not reach any more values, such as 400 sec/km, having maximum values in the replication of the order of 40 sec/km, evidencing a reduction of 59% in the overall delay time, passing from 41.11 sec/km to 16.97 sec/km. In the average graph, the maximum value reached by the system was 23.5 sec/km compared with the 209 km/h presented in scenario 3A.

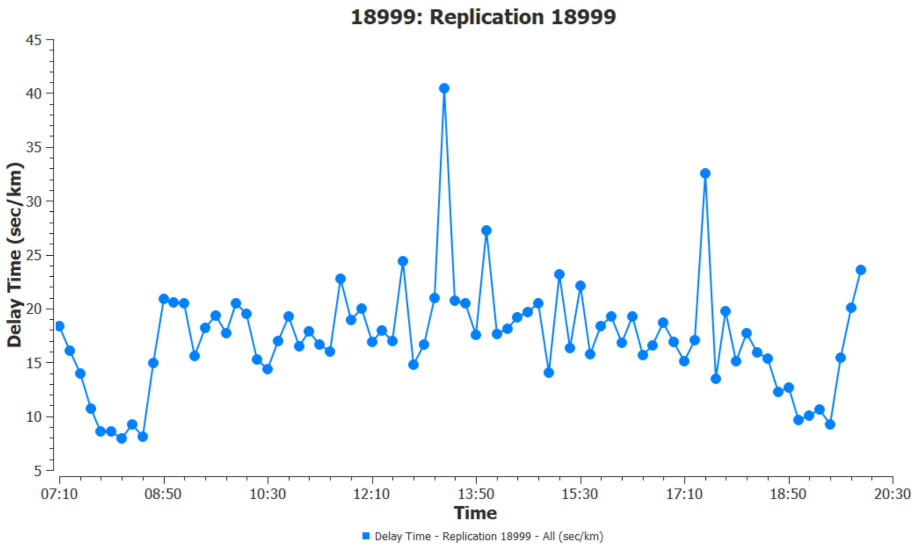


Figure 156. Delay time graph: Scenario 4, replication 1

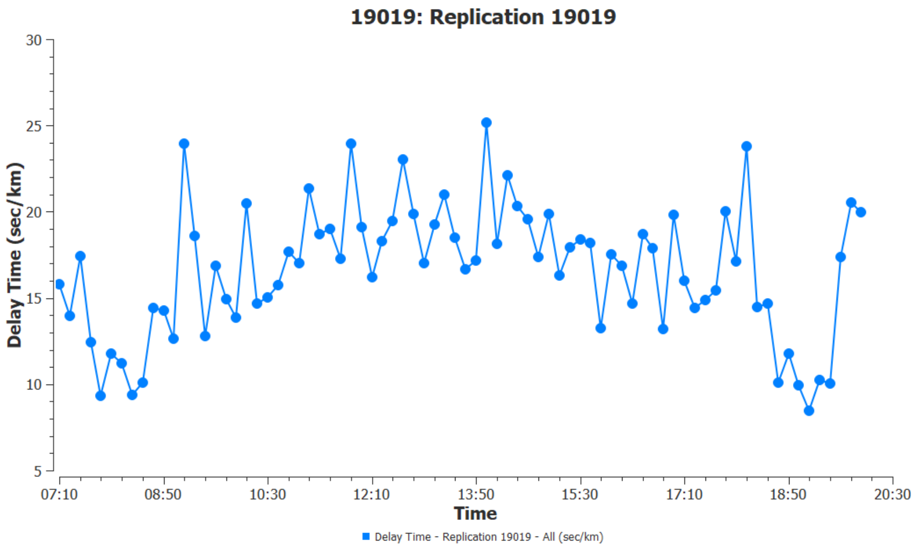


Figure 157. Delay time graph: Scenario 4, replication 2

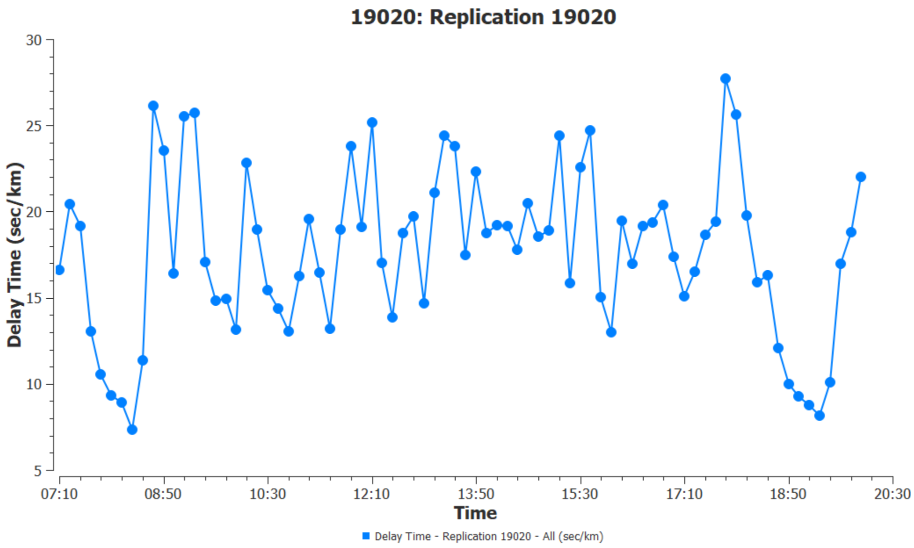


Figure 158. Delay time graph: Scenario 4, replication 3

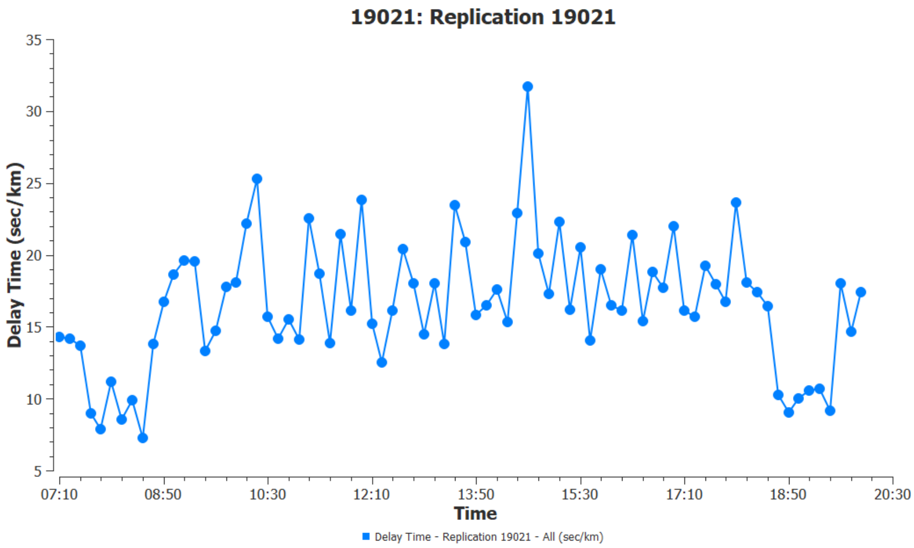


Figure 159. Delay time graph: Scenario 4, replication 4

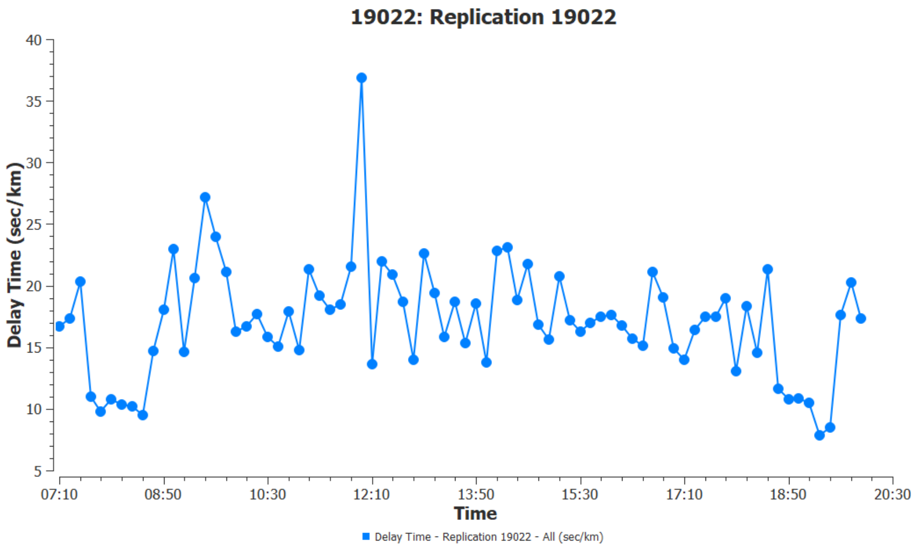


Figure 160. Delay time graph: Scenario 4, replication 5

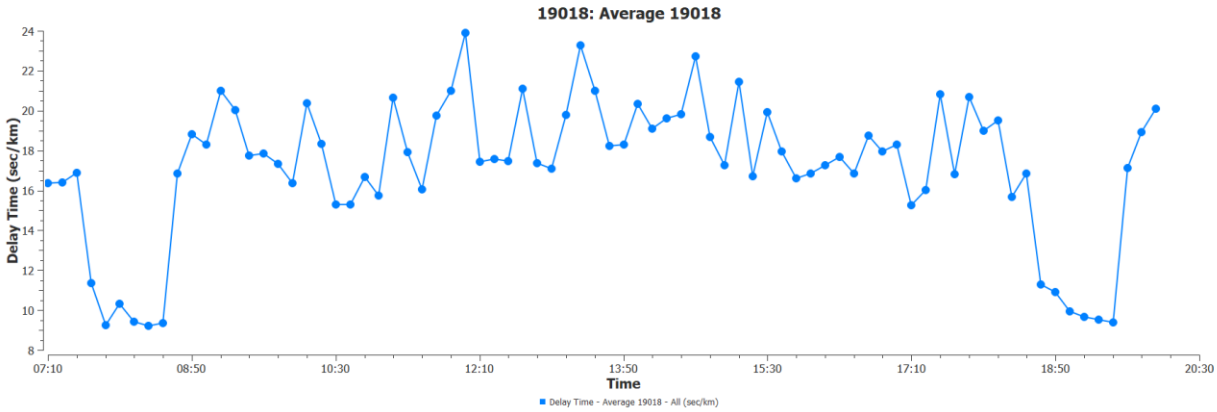


Figure 161. Delay time average graph scenario 4: Repl. 1 (18999), Repl. 2 (19019), Repl. 3 (19020), Repl. 4 (19021), Repl. 5 (19022)

Regarding the speed, as also happen with the flow and delay time, the tendency was to make more consistent the behavior, it was noticed a decrement of 3.6 km/h in the overall velocity in respect to the first scenario, being now 46 km/h respect to 49.6 km/h but an improvement of 35% respect the critical scenario 3A, passing from 34 km/h to 46 km/h. The minimum value reached in the average chart was 43 km/h. Figure 168 shows the situation at the peak hour period simulated with the software, which is evident in the relief of traffic congestion.

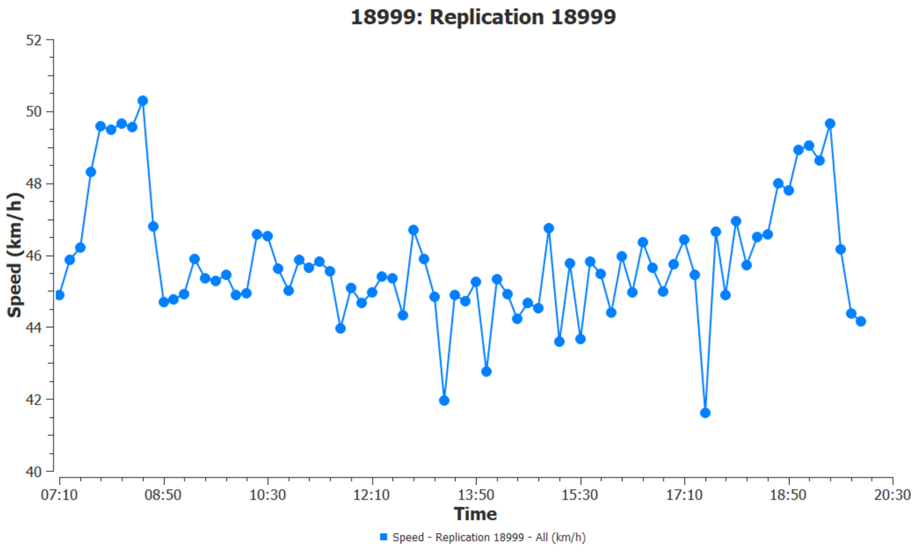


Figure 162. Speed graph: Scenario 4, replication 1

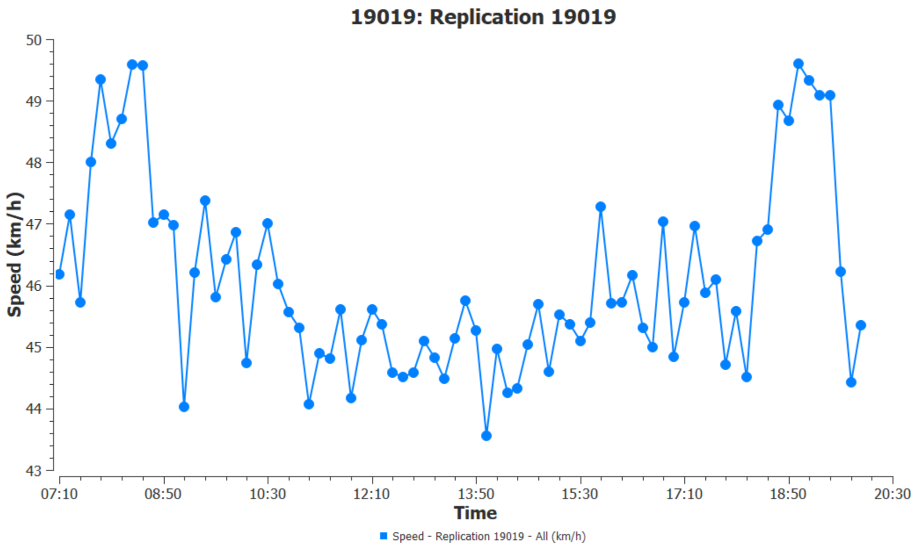


Figure 163. Speed graph: Scenario 4, replication 2

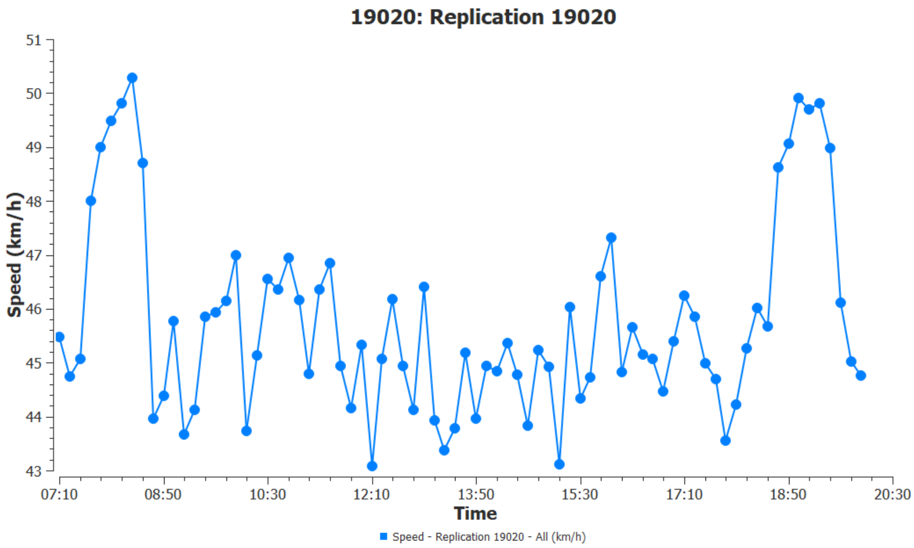


Figure 164. Speed graph: Scenario 4, replication 3

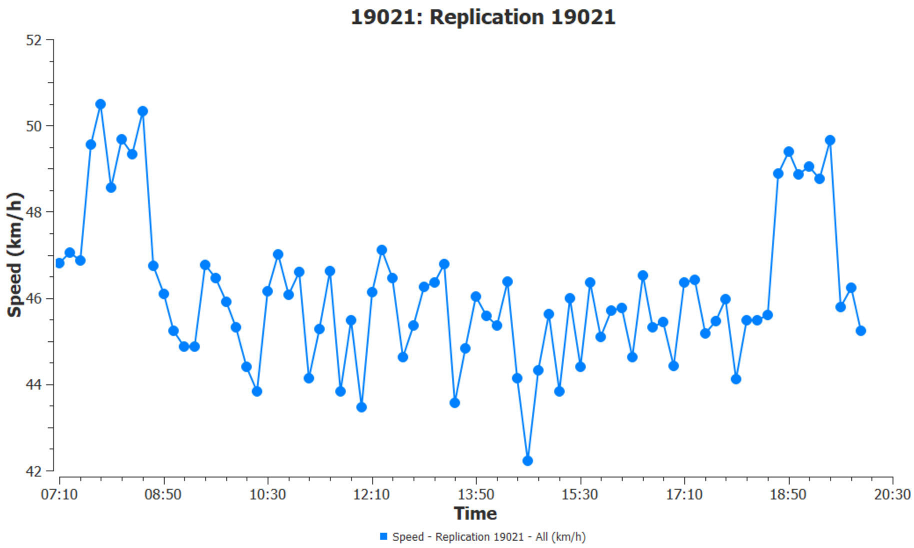


Figure 165. Speed graph: Scenario 4, replication 4

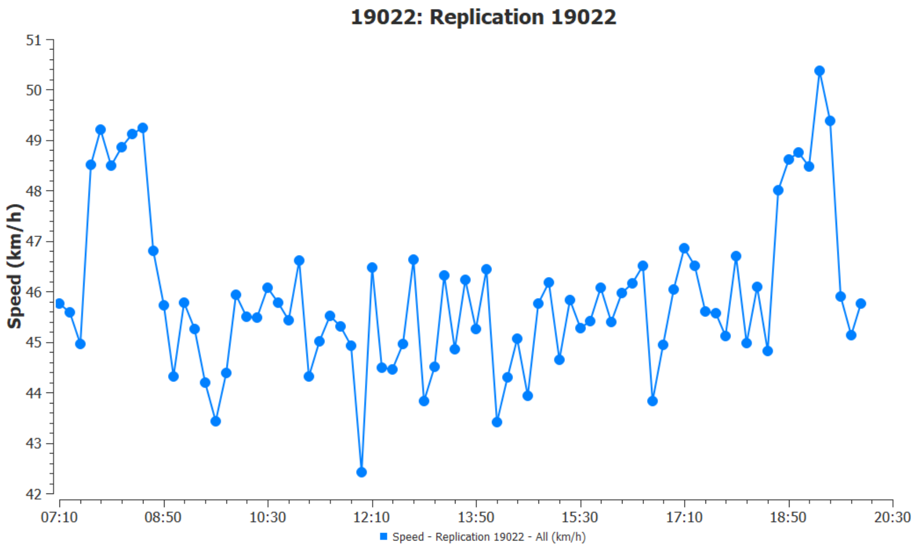


Figure 166. Speed graph: Scenario 4, replication 5

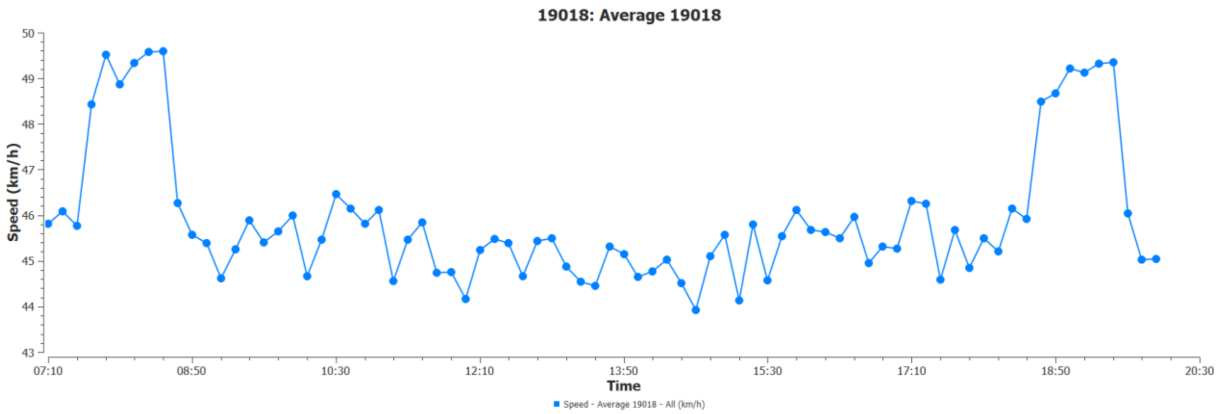


Figure 167. Speed average graph scenario 4: Repl. 1 (18999), Repl. 2 (19019), Repl. 3 (19020), Repl. 4 (19021), Repl. 5 (19022)

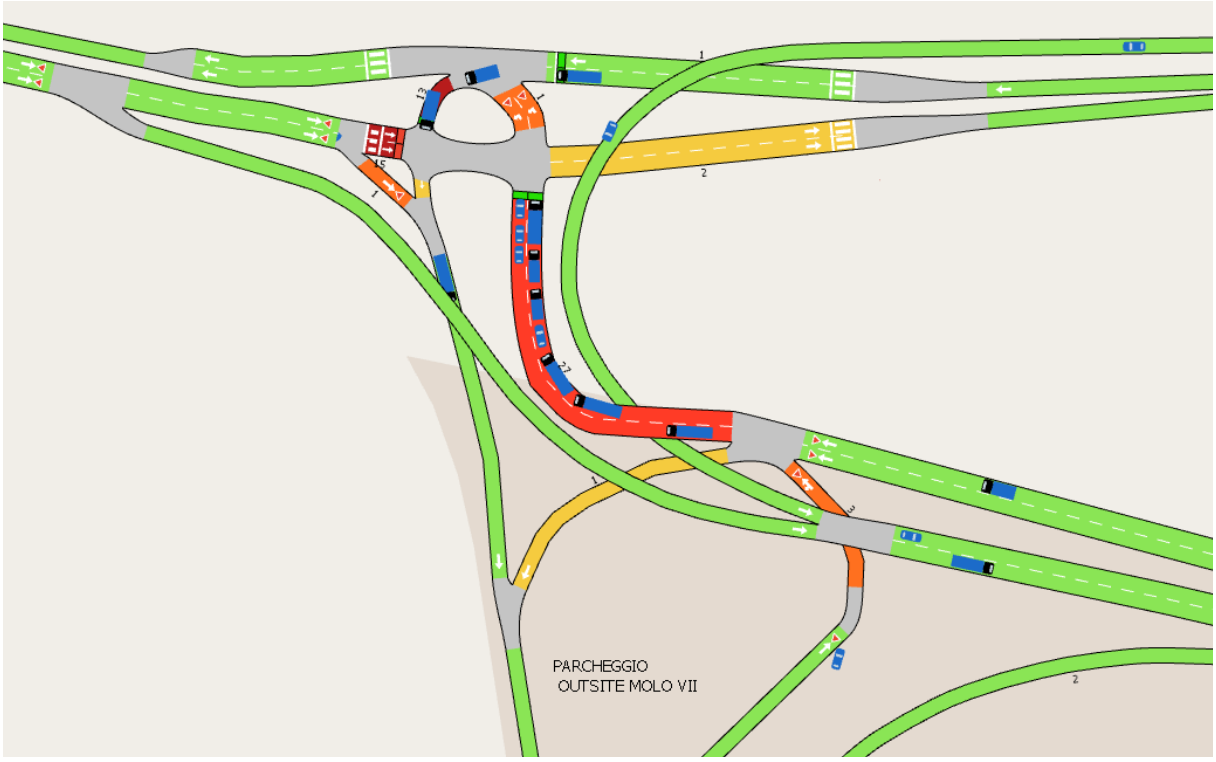


Figure 168. Software image of scenario 4 situation

In order to understand how significant the results of the proposed ITS solution could be, it was decided to carry out a series of additional scenarios aiming to compare the actual effect of the new configuration (scenario 4). As a first step two extra scenarios were developed, taking as a reference scenario 3A. The first scenario was set with a 30% traffic increase while the second one was majored of 50%. These two scenarios were destinated to understand how the constant traffic increase could affect the entire system in which there has not been an improvement with ITS. In the following tables the average values of flow, delay time and speed are reported.

Table 23. Average flow values for NO ITS scenarios

AVERAGE FLOW - NO ITS	
SCENARIO	FLOW (veh/h)
Scenario 2 (2011 situation)	1366
Scenario 3A	1667,54
Scenario 3A +30%	1842,77
Scenario 3A +50%	1952,62

Table 24. Average delay time values for NO ITS scenarios

AVERAGE DELAY TIME - NO ITS	
SCENARIO	DELAY TIME (sec/km)
Scenario 2 (2011 situation)	16,39
Scenario 3A	41,11
Scenario 3A +30%	68,51
Scenario 3A +50%	94,32

Table 25. Average speed for NO ITS scenarios

AVERAGE SPEED - NO ITS	
SCENARIO	SPEED (Km/h)
Scenario 2 (2011 situation)	47,07
Scenario 3A	44,47
Scenario 3A +30%	41,3
Scenario 3A +50%	39,87

Then these four scenarios were rearranged with the scenario 4 configuration, which means applying the proposed ITS solution of a variable message system in the local broadcast system to update all the users about traffic conditions in the critical zones. ITS would communicate to heavy vehicles driver the necessity of not transiting into the critical zones during the most congested hours, as explained before. In the following tables the average values of flow, delay time and speed are reported.

Table 26. Average flow values for ITS scenarios

AVERAGE FLOW - ITS	
SCENARIO	FLOW (Veh/h)
Scenario 2 (2011 situation)	1352
Scenario 3A	1673,72
Scenario 3A +30%	1893,54
Scenario 3A +50%	2008,08

Table 27. Average delay time for ITS scenarios

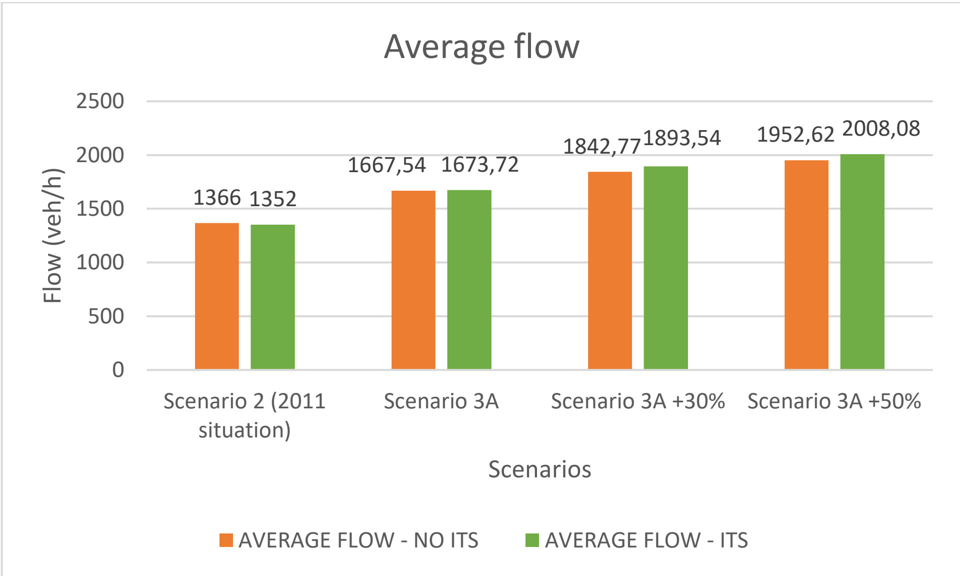
AVERAGE DELAY TIME - ITS	
SCENARIO	DELAY TIME (sec/km)
Scenario 2 (2011 situation)	12,43
Scenario 3A	16,97
Scenario 3A +30%	32,93
Scenario 3A +50%	62,13

Table 28. Average speed for ITS scenarios

AVERAGE SPEED - ITS	
SCENARIO	SPEED (km/h)
Scenario 2 (2011 situation)	47,79
Scenario 3A	45,99
Scenario 3A +30%	43,77
Scenario 3A +50%	42,63

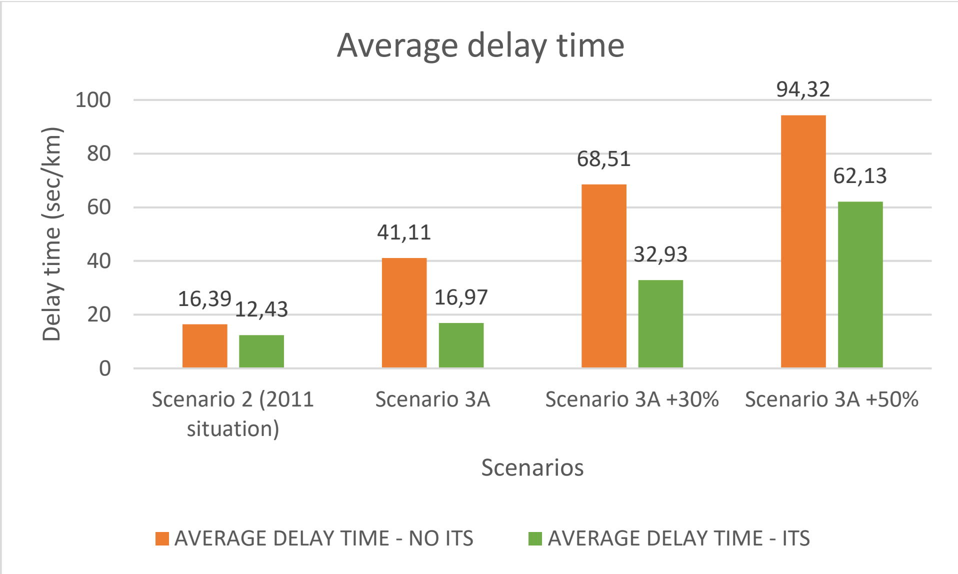
With an eye toward comparing the situations, a histogram was developed with these two conditions. The objective was to see the solution's actual incidence in the current conditions and see how the implementation of this ITS system would behave when having a traffic increase of 30% and 50%.

Figure 169. Average flow's histogram



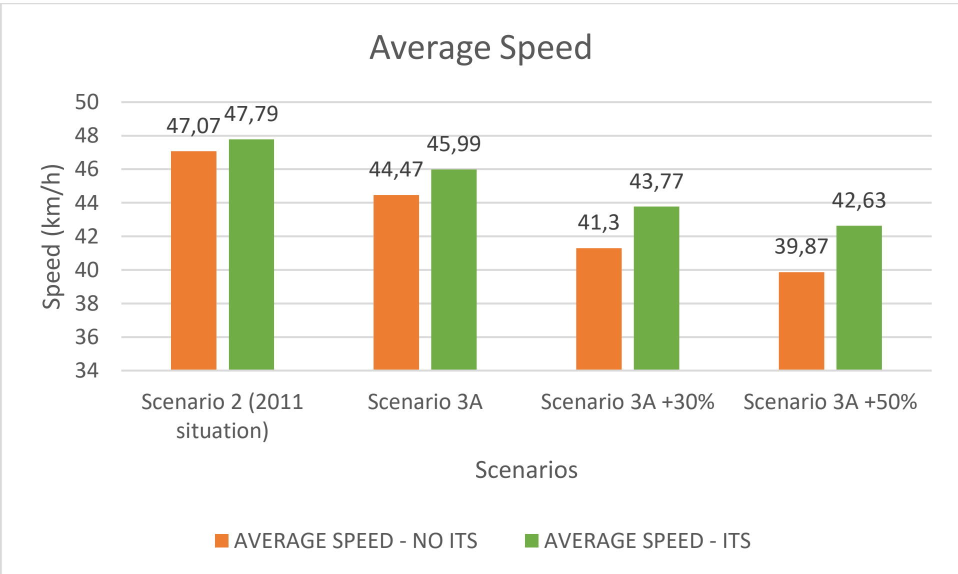
The first figure clarifies that in both scenarios, we have the same quantity of flow; therefore, the differences between the delay times and speed indicators will not depend on differences in the flows but on system's performance.

Figure 170. Average delay time's histogram



The average delay time, as expected, has a significant reduction. Before ITS implementation, delay dramatically increased along with the flow, reaching worrying values considering that we are evaluating the average values. In general, with the ITS implementation, there is an important reduction of 42% on average. Having 24 % reduction of the delay time for scenario 2, 59% for scenario 3A, 52 % for scenario 3A +30% and 34% for scenario 3A 50%.

Figure 171. Average speed's histogram



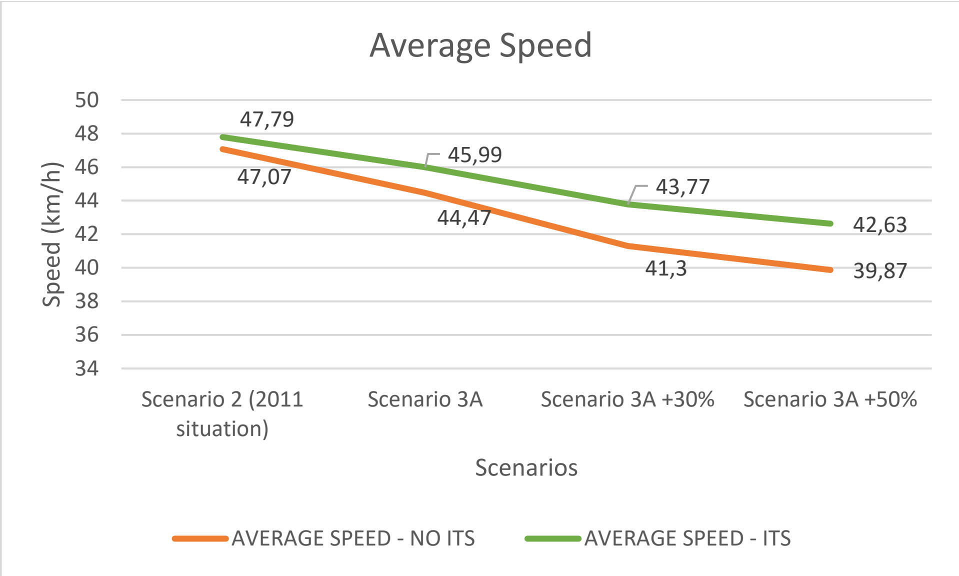


Figure 172. Average speed graph

The average speed, being the other side of the same coin, is also vastly improved. With the ITS system implementation, even significant flows affect less the average speed of the system. In Figure 163, it can be seen that the slope for ITS scenarios is less steep, with an average improvement of 5%.

6. Conclusions

The present Master thesis permit us to observe and understand the impact that an ITS system has when applied to a scenario with unfavorable traffic conditions, allowing the system to undertake more extensive flows decreasing delay times while improving speed values.

The model was developed using a traffic simulation software called AIMSUN, which helps us setting realistic conditions to arrange various scenarios with different characteristics to have a more comprehensive view of the situation. This software is characterized by a series of skills that allows the user to develop a super large-scale model only by making detailed simulations where necessary, getting accurate results with low calibration effort.

The simulation was run in four different scenarios. The first scenario was set to describe system's initial conditions, applying only the conditions of the urban private sector, using the O/D matrix provided by Trieste's municipality. This scenario was done to observe and analyze how much the traffic generated by the port would affect the general system. As a result, it was seen that the initial system does not present critical conditions having acceptable delay times and speed values. The second scenario was done using the traffic characteristics reported in the "Piano Regolatore Portuale Del Porto Di Trieste," aiming to simulate the 2011 port's conditions. In this way, the heavy-duty vehicles matrix was modified, introducing a significant flow that, as expressed in the PRP, is generated by the port. In this scenario, it was able to appreciate the impact that such a traffic increment may have on the overall system, there were more worrying results, but they still did not represent the actual conditions.

After some research, it was seen that many port cities around the world share similar critical conditions dealing with the demanding traffic events in the port's surroundings due to the disproportional amount of traffic that the naval gigantism is generating. Therefore, in this order of ideas, the third scenario was set by increasing a 40%; this value was chosen after analyzing different graphs provided by the course Sistemi di trasporto e logistica esterna dictated by Prof. Bruno Dalla Chiara and Atlas Magazine. In addition, taking into account that not all traffic data was available, particularly the primary node's traffic light, three extra sub scenarios were set simulating the conditions of 3 different semaphoric cycles. This scenario, in general, presented significant results; it was seen in the different replications concerning values of delay time and speed. The average speed and the average delay time suffered a worrying decrement and increment, respectively, compared to the previous scenarios. It was also seen the importance of the semaphoric cycles optimization. It is suggested that further research analyze this scenario with real data and optimized cycles developing strategies relates with the traffic lights optimization. The idea would be to set an strategy that would use an optimized set OF semaphoric cycles that will be activated when the traffic conditions require it. In this order of ideas, it can be determine a set of traffic conditions ranges, and for each group an optimized semaphoric cycle would be designated, the strategy would activate a determined semaphoric cycle when the traffic conditions linked to that cycle are occurring.

The last scenario proposed a variable message system that would be carried out through a local broadcast system to keep updated the users about traffic conditions in the critical zones—communicating to heavy vehicles driver the necessity of not transiting into the critical zones during the most congested hours. The improvement with the scenario was evident, having a 59% reduction of the average delay time and a 35% speed improvement with respect to the most critical scenario (Scenario 3A). Aiming to have a clearer view of the new situation, a sensitivity analysis was performed, adding two scenarios with an incrementation of 30% and 50% of the traffic respect with scenario 3A. The ITS system arrangement was also tested with these two new scenarios to see how the ITS solution would respond to the continuous increment of the traffic that would keep happening due to the constant increment of naval transit. It was observed the constant betterment in the different scenarios. From scenario 2 to scenario 3A+50%, it was seen significant reductions of delay time and optimization of the speed. As next step it is recommended to re-evaluate the model also using the rerouting as a strategy given that it is considered as an optimal admixture to improve the throughput of the system.

In conclusion, it can be said that ITS solutions represent a more accessible and more costless solution than an eventual rearrangement of the urban infrastructures in order to adapt the system to the continuous increment of the traffic. Moreover, the possibility of increase the infrastructure is not always possible or, as seen in state of the art, sometimes does not apport an improvement but a decrement in the throughput.

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